AD704608

DASA 2303-II

HIGH ALTITUDE BLAST GENERATION SYSTEM
PART II
DESIGN AND ECONOMIC STUDY

prepared for

DEFENSE ATOMIC SUPPORT AGENCY
WASHINGTON, D. C. 20305
CONTRACT NO. DA-49-146-XZ-573

sponsored in part by

ADVANCE RESEARCH PROJECTS AGENCY
NUCLEAR TEST DETECTION OFFICE
WASHINGTON, D. C. 20301
ARPA ORDER NO. 908

DECEMBER 1967

GATX
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DASA-2303 II

HIGH ALTITUDE BLAST GENERATION SYSTEM

PART II

DESIGN AND ECONOMIC STUDY

Final Report

December 1967

by

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ABSTRACT

A program was conducted to determine the technical and economic feasibility of a high altitude blast generation system using detonable gases contained in balloons. The purpose of this system would be to produce a blast and shock environment at altitudes of up to 100,000 feet for in-flight missile and aircraft vulnerability testing and for atmospheric nuclear blast detection studies.

This report describes the results of this program in two parts: Part I (bound separately) describes the theoretical and experimental work; Part II describes a preliminary design and economic study of the hardware required for the system. Both Parts I and II were conducted simultaneously.

For Part I, computer codes were developed to predict the detonation properties and resultant shock wave-air interaction phenomena at low ambient pressure and temperatures. An experimental program was then conducted which verified the theoretical predictions by detonating 5 and 10 foot diameter balloons filled with either methane-oxygen or hydrogen-oxygen mixtures at simulated altitudes up to 100,000 feet (low temperatures were not simulated).

For Part II, attention was given to the balloon design, the gas handling system, the launch and handling equipment, the effects instrumentation and flight control, the instrumentation recovery system and possible test sites required to physically implement this blast and shock generation technique. Cost estimates to field a single test ranged from \$191,460 for a one ton explosive yield equivalent at 50,000 feet to \$317,200 for a twenty ton yield at 50,000 feet. Costs for subsequent tests would be reduced since most of the equipment would be reusable. The White Sands Missile Range, New Mexico is recommended as being the best suited to support and conduct all proposed tests.

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SECTION 1

SUMMARY AND CONCLUSIONS

The General American Research Division has developed a blast generation and shock simulation technique, using the spherical detonation of a combustible gas mixture initially contained in a balloon (DASA 1792-I).

The part of the program reported herein describes the results of a preliminary design and economic study of a High Altitude Blast Generation System.

The High Altitude Blast Generation System makes use of the fact that certain combinations of detonable gas mixtures are buoyant. Therefore, an inherent advantage to the system is that the detonating medium is also the lifting medium.

Several system flight configurations were investigated in detail during the program. Two of these systems separate the fuel from the oxygen during filling and launching by either a ballonet or tandem balloon technique. The other systems allow the gases to be mixed during the filling and launching operations. Although all of the systems are considered feasible with each having its advantages and disadvantages, the system recommended by GARD is a natural shaped balloon system. This system mixes the gas during filling. Upon release it lifts an instrumentation train consisting of a packed recovery parachute attached to an instrumentation package. The instrumentation package would contain the necessary components to support the blast effects pressure sensors in the train and the command and control requirements of the system. This report recommends that the instrumentation equipment be comprised of available off-the-shelf, IRIG compatible hardware with the exception of the flight programmer which would have to be developed for each mission. The recommended gas loading system is of the same proven type presently being used on the Simulating Large Explosive Detonable Gas Experiments (SLEDGE). The suggested handling and launching scheme is an AFCRL developed system.

Two test sites recommended are: White Sands Missile Range, New Mexico for initial system development and Kwajalein Test Site for a fully operational system.

An economic study of each component in the High Altitude Blast Generation System has revealed the balloon as the major item of expense. Other major items of expense secondary to the balloon are: the instrumentation system, test site support, and labor. Because of the many variables and combinations involved, a specific cost summary becomes difficult to estimate. However, by selecting the alternate schemes or systems of interest an immediate cost summary may be obtained at the end of each system discussion. So that some order of magnitude may be established, Table 1.1 represents the potential range of costs per event. The maximum total reflects the largest yield (20 tons) at the highest altitude (50,000 ft) using a stainless steel gas loading system, and a primary and backup instrumentation system. The minimum total includes the lowest yield (1 ton) at the same altitude (50,000 ft) using a low carbon steel gas loading system and a minimum amount of instrumentation.

TABLE 1.1

PROBABLE RANGE OF HIGH ALTITUDE SLEDGE FIRST DIRECT COSTS

	Minimum Cost (1 ton, 50K ft.)		Maximum Cost (20 tons, 50K ft.)
Balloon	$ 50,000		$ 70,000
Launching and Handling Equipment		$ 10,000	(Maximum)
Gas Loading Equipment	6,000		43,000
Gas (Methane-Oxygen)			11,200
(Hydrogen-Oxygen)	1,460		
Instrumentation and Flight Control	58,000		67,000
Recovery	1,000		6,000
Test Site - (White Sands Missile Range)		30,000	(Average)
Logistics	5,000		10,000
Labor	30,000		70,000
TOTAL	$191,460	-	$317,200

In conclusion, the development of a high altitude blast generation system appears feasible from both a technical and economic standpoint. The mobility and versatility of the suggested system allows many areas of practical application.

SECTION 2

DESIGN AND ECONOMIC STUDY

The overall objective of the study was to furnish sufficient technical and economic data to permit a knowledgeable decision regarding the overall practicality of a high altitude blast generation system using SLEDGE. The objective was fulfilled by conducting a conceptual design and economic study to determine the hardware requirements and costs of a high altitude blast generation system. This study included the conceptual design of the balloon, and associate hardware equipment. Possible test sites were surveyed to determine practical locations for conducting the full scale tests.

2.1 Balloon and Associated Equipment

The conceptual design and economic study of the balloon and associated equipment is described below in five basic groups: balloon system, handling and launching equipment, gas loading system, instrumentation and flight control, and recovery system.

2.1.1 Balloon

A qualitative study into the requirements of the balloon for a high altitude blast generation system using SLEDGE has revealed unique problems for this application. First, the quantity of gases for a particular flight are determined by the desired explosive yield. This in turn establishes the gross lift available. (See Figure 2.1) This is somewhat contrary to normal balloon flights where the quantity of gas is determined by the operational lift requirements. Second, the desired explosive yield along with a selected altitude establishes the balloon diameter required to contain the gases. (See Figures 2.2, 2.3) The concept here is to provide as small a balloon as possible. The gas balloon will be detonated either as it passes through the design altitude or after it has established an equilibrium or "floating" altitude as is done in normal balloon flights. Although venting the gases would reduce the effective yield, injecting more gas during the filling operation would compensate for this effect should the need arise. Finally, by knowing the altitude, explosive yield (gross lift) and balloon weight (based on diameter and material weight $\approx$ .015 lbs/ft^2), the maximum payload may be determined. (See Figures 2.4, 2.5.) Practical limits placed by the state of art in balloon operations for large balloons, maximum lift on balloon materials, and minimum payload weights are shown on the figures.

Other than that mentioned above, the requirements of a detonable gas balloon are similar to the ordinary balloon used in conventional balloon flights. A balloon is most vulnerable to the sailing effects of the wind acting upon the undeployed material, especially during initial launch phase. For this reason a taut balloon concept provides the most reliable launch technique. With gaseous detonations near ground level, the concept used to date has been to rapidly fill a balloon with air into which a ballonet has been incorporated until the final spherical shape is achieved. The detonable mixture is then injected on one side of the ballonet while the air is vented from the other side. (See Figure 2.6A) A slight internal balloon super pressure is maintained, during this process. This keeps the external balloon structure taut. This concept, with modifications, has possible application to high altitude SLEDGE. A larger, horizontal ballonet balloon would be rapidly filled with air as before but only the sea level volume of detonable gas would be injected. Without any undeployed material to be affected by the wind, the balloon, already in its final spherical shape, would be less susceptible to damage during launch. As the balloon rose to altitude, the gas would gradually expand and assume a progressively larger share of the total (constant) volume. On the other side of the ballonet, the air would be continuously vented. Relief valves, to control the venting of the air, would be constructed so as to maintain a slight overpressure in the balloon, thereby insuring a taut external geometry. The concept described thus far appears feasible for balloon sizes up to 200 ft. in diameter and altitudes up to 35,000 feet.

Another technique applicable for balloons over 200 feet in diameter and altitudes in excess of 35.000 ft., would be a tandem or "bar-bell" balloon concept. (See Figure 2.6B) The basic configuration would be a spherical balloon reefed in the middle with gas pockets at each end. These gas pockets would be just large enough to accommodate the sea level volume of fuel gas in one end and oxygen in the other. As the system ascended to altitude, the gases would expand inflating the additional material contained in the reefed section until a spherical shape was assumed. The reefing would have to be designed to deliver only enough additional material so that a slight overpressure was maintained in the balloon ends. The use of the tandem balloon concept is predicated on the assumption that the fuel and oxygen gas will mix during the ascent of the balloon. The gas mixing process would have to produce a homogeneous mixture before a detonation at altitude is assured An experimental program was conducted to determine the mechanism for mixing in the tandem balloon concept. (See Part I, bound separately, of this report.) The only method, experimentally, that produced detonation was to allow the gases sufficient time for mixing. The nominal mixing time required to produce a detonation in the model balloon would scale approximately to 6000 minutes for the actual case.

The advantages of the ballonet-balloon concept are as follows: it has previously been used so that an experience factor may be applied to its development; the system employs the taut balloon concept throughout the entire flight to guard against the destructive forces of the winds; the balloon would be most suitable for low altitude (free or tethered) applications. Some disadvantages are: large balloons would present handling problems; the ballonet may add an excessive weight penalty as progressively higher altitudes are considered. Advantages of the "bar-bell" balloon concept are: it is most suitable for high altitude applications; the separation of gases provides a safety factor during the launch phase; this system affords a simplicity in design. The disadvantages are: the gas mixing time is excessive; and the minimum altitude restriction is approximately 35,000 ft. The minimum altitude of approximately 35,000 ft was arrived at by comparing the volume of a given diameter balloon with the volume of a minimum reefed balloon. The ratio of these volumes is found to be approximately 1/4. This indicates the volumetric expansion of the gases,due to a decrease in ambient pressure, would have to be equal to, or greater than, a factor of four. If the volume of the gases at altitude were, for example, three times as much as the volume of gases at sea level there would be insufficient volumes to contain the gases initially and still provide a reefed balloon. Therefore, because pressure and volume are inversely proportional, the altitude where the pressure ratio is 1/4 or 0.25 is 33,800 ft. (or for nonspherical balloon ends approximately 35,000 ft.)

A modification to the ballonet-balloon concept was also considered. This modified concept, like the "bar-bell" balloon concept, would improve the safety of handling by keeping the oxygen and fuel gas separated from each other during launching, and initial ascent. This concept would require a secondary partition, which would be ruptured at a predetermined altitude. (See Figure 2.6C) The balloon configuration would be similar to the ballonet-balloon concept, i.e., a spherical balloon with a horizontal ballonet attached at the diametral plane. In this case however, an additional or secondary ballonet would be included on the detonable gas side. This secondary ballonet would contain the fuel or buoyant gas at the upper most part of the balloon so the lifting forces would act along the vertical center line of the system. By necessity, the material rupture strength of the secondary ballonet would be much lower than that of the parent balloon. The operational sequence would be to rapidly fill the air side of the balloon to establish a taut shape. The sea-level volume of oxygen would then be injected between the main and secondary ballonet while air would be vented to maintain the same total volume. Finally the sea-level volume of fuel/ buoyant gas would be loaded into the chamber created by the secondary ballonet. As the system ascends to altitude, the fuel gas would gradually expand to consume the entire secondary ballonet chamber. The altitude at which the rupture occurred would depend upon the material strength of the secondary ballonet and the ratio of the chamber volume to the sea-level volume of fuel gas. Because the volume of the secondary ballonet chamber (approximately equal to the sea-level volume of gas) is relatively small as compared to the total system, the secondary partition need not contribute much weight. However, as in the "bar-bell" balloon concept, the process of mixing of the two gases must be completed before the time of intended detonation. Whether a sufficient period would exist to produce a homogeneous mixture is unknown for this third concept.

A fourth concept was considered as an alternative to the ballonet-balloon concept for low altitudes. This concept consists of a basic balloon with no reefing or ballonet. There are significant advantages to this concept from the standpoint of balloon fabrication, reliability and cost as well as in simplification of the inflation equipment and procedures. Primarily, however, there is the simplicity of fabrication in comparison to the ballonet balloon. Without a ballonet and air chamber, there are a minimum number of appendices, with no requirement for air relief safety valves, air inflation tubes and air inflation ground support equipment. This inherently provides a simpler, more reliable, and less costly balloon.

The disadvantages of this concept over the ballonet-balloon concept is that the balloon does not become taut until the detonation altitude is reached. The time that the balloon is not taut during ground inflation may be reduced by increasing the transfer rate of the gases over that used during Operation DISTANT PLAIN (DASA 1945).

In conclusion, of the four techniques presented above, the fourth appears best suited to the high altitude SLEDGE because of its simplicity and past performance. The costs for the four types of balloons are presented in Figure 2.7 based on the present state-of-the-art in balloon materials and construction methods. These costs were obtained from a balloon manufacturer, on a preliminary budgetary basis only.

2.1.2 Handling and Launching Equipment

It is recognized that different handling and launching techniques are required for the ballonet balloon and the tandem or "bar-bell" balloon. The handling and launching equipment required for a ballonet balloon has been under development for Project SLEDGE (DA-49-146-XZ-400). For application on the high altitude SLEDGE, the ballonet balloon would be released from the gas filling pipes after being filled and reeled out to an altitude ($\sim$200 feet) which would permit the deployment of the instrumentation train below the balloon. After the instrumentation train is properly deployed, the balloon is released and allowed to ascend in free flight on its mission. Much of the development work on this deployment technique has already been reported in previous SLEDGE reports and will not be repeated here.

Little, if any, experience is available on handling and launching detonable-gas-filled tandem or "bar-bell" balloons. Since this concept has much promise for blast and shock applications above altitudes of 35,000 feet, the major effort of this program was directed to conceptualizing a technique for handling and launching this balloon.

This section describes a primary and alternate scheme for both local and remote handling and launching of a tandem or "bar-bell" balloon. The underlying feature of both schemes is that both provide a degree of freedom in azimuthal positioning of the instrumentation payload train and balloon in line with the prevailing launch area surface-winds. The primary scheme differs from the alternate in that it does not employ tether lines attached to load patches on the buoyant fuel cell, whereas the alternate scheme does. The only fixed component of equipment is the oxygen filling system which is placed beneath ground level. The oxygen filler port at ground level is the azimuth pivot point for rotating the entire array of equipment to line up with the prevailing surface winds. All other associated launching, tethering, and winching equipment are truck mounted. This allows the necessary mobility to take up varying azimuthal stations using the oxygen filler port as the pivot point. Reasons for aligning the payload train parallel to the surface wind vector are to minimize balloon sway after a state of buoyancy is attained thus preventing the payload train from dragging on the ground during intial ascent.

Launch control operations in the primary and alternate launch schemes for the "bar-bell" balloon are divided into two control phases, namely local and remote.

The first phase initiated at the launch site is the local control phase. This phase covers activities related to the positioning of winch trucks, balloon trailer bed, and fuel-gas trailers. It also covers the connecting of winch tether lines, instrumentation/recovery system payload lines, and remote operating systems check-out, plus inflation of the buoyant fuel gas pocket of the tandem balloon. Completion of the buoyant fuel gas-pocket inflation marks the end event of local control handling activities. All personnel are to be removed from the launch area at this point to a physically safe distance.

The second phase is the remote control phase. It is initiated at the start of the oxygen filling operation. During the oxygen filling, all tether-line winch tensioning is remotely controlled to keep the inflated buoyant fuel gas bubble in position directly above the oxygen filler port as much as possible. Upon completion of the oxygen filling operation, the oxygen inflation valve closes off any reverse flow into the filler port thereby sealing the gas pocket. The next operation is the remote disengagement of the balloon from the oxygen filler port. This event now places the balloon under full tethering control of the winch operators. The remote winching operation is activated so as to allow the balloon to rise and traverse the distance (under captivity) from the oxygen filler port area to a position vertically above Winch Truck No. 2 as illustrated in Figure 2.8. The winches on Truck Nos. 1 and 2 are then regulated so that the vertical position of the balloon above Truck No. 2 is maintained while paying out an amount of line from Truck No. 2. This is done to make certain that the now vertically aligned payload will clear all obstructions when final lift-off takes place. The next procedure is to take the final lift-off reading from a load cell (tensiometer) situated in the payload train below the intrumentation package. The final procedure remains to excite tether-line cutters thereby freeing the balloon for free flight ascent to altitude.

2.1.2.1 Primary Launch Technique

The primary launch plan shown in Figure 2.9 incorporates a system similar to the AFCRL balloon deployment roller mechanism. The deployment mechanism and the packaged balloon are mounted on a flat-bed trailer as shown. Pre-packaging of the balloon is such that the lower portion with the oxygen fill ring attached, can be removed from the balloon box and draped over the side of the trailer and connected to the oxygen fill port.

The payload which includes the instrumentation package, the recover parachute, and the instrumentation line is laid on the ground to its full length and is aligned parallel to the average direction of the prevailing surface winds.

Tether lines from two truck mounted winches are then fastened into position; one being directly connected to the triangular plate, and the other to the instrumentation-package base connection point. The opposite end of the instrumentation line is also connected to the triangular plate. Finally, the triangular plate is connected to a semi-circular swivel which is attached to the oxygen fill inflation valve at the south polar cap of the balloon. When all tether and payload line connections have been accomplished, line slack can be taken up by the winches and buoyant fuel gas filling can be initiated.

The buoyant-fuel-gas pocket is deployed through the rollers, under local control operation to a point where the two filler ducts can be connected to the fuel gas trailers. During the fuel gas filling operation, adequate protective clothing will be worn by all personnel near the balloon and fuel gas lines. At this point, the fuel gas is then transferred from the trailers into the fuel gas balloon pocket. It should be noted that the resultant left can be tailored during fuel filling by the proper choice of gas constituents as described in Section 2.3, Part I. The balloon material is then gradually deployed through the rollers until the required volume of buoyant fuel gas has been transferred into the gas bubble. The filler ducts are then tied off and tape sealed to prevent leakage. Subsequent to filler duct sealing, the balance of the reefed balloon section and the uninflated oxygen pocket are then passed through the rollers. The rollers are released when the final portion of the balloon is deployed through them, thus allowing the inflated fuel gas bubble, the reefed section, and uninflated oxygen pocket to stand erect over the oxygen filling port. This event essentially marks the end of local handling operations whereupon all personnel and nonessential equipment are evacuated from the immediate launch area.

Commencement of the remote control operation begins with the oxygen gas filling. After the oxygen fill is completed, the balloon is remotely released from the pipe filling port. This allows the balloon to rise slightly bringing the connected lines under tension in restraining the net buoyant lift force of the fuel gas bubble (Figure 2.8). The winch on Truck No. 1 is then remotely activated, gradually paying out line causing the balloon and payload section to rise from its ground orientation until the entire balloon/payload system is vertically tethered over Winch Truck No.2. At this point the tether line from Winch Truck No. 1 is released from the balloon by a line cutter. Truck #1 affords mobility to the system and the winch on truck #1 allows the entire system to be raised to a sufficient height so that upon final release the payload will not contact the ground. With this arrangement the wind ma' blow in either parallel direction.

With the balloon/payload system standing erect over Winch Truck No.2, a net lift force reading is taken from an in-line tensiometer. After the lift force reading is acquired a line cutter situation above the tensiometer and below the instrumentation package is fired, thereby freeing the balloon for free flight ascent to altitude.

2.1.2.2 Alternate Launch Technique

The alternate launch plan shown in Figure 2.10A makes use of two tether lines attached to a number of load patches on the fuel-gas bubble of the balloon. These lines are used in place of the balloon deployment roller mechanism to control the buoyant fuel bubble deployment. Launch vehicles required for this plan are two winch trucks, and a flat-bed trailer to transport and act as a deployment platform for the balloon. Figure 2.10A shows the launch control vehicles, payload train, flat-bed balloon trailer, and gas trailers positioned normal to the average surface wind direction. The flat-bed trailer is positioned with the tail-gate just off the O_2 fill port, and winch trucks at each side. Pre-packaging of the balloon would be similar to that used in the primary technique. This method of packing should allow access to the oxygen fill ring at the south polar cap of the balloon on one end of the box and to the north polar cap and filler ducts of the fuel-gas pocket at the other end of the box. The appropriate connections may then be made to their respective gas sources. Both tether lines are then connected to load patch connection points on the fuel-gas bubble and fuel-gas loading commences. As the fuel-gas bubble becomes buoyant it is allowed to deploy from the box paying out tether line as it rises. As in the previously described system, the bouyant lift force can be controlled by tailoring the fuel gases, i.e., a fuel gas with a higher molecular weight can be introduced to reduce the lift force. When the required volume of fuel gas has been injected into the balloon the filler ducts are tied off, disconnected from the gas source, and taped sealed as shown in Figure 2.11. The winch trucks are gradually moved until they position the balloon over the oxygen fill port. The tether lines are then winched out gradually, allowing the balloon to assume a vertical posture over the oxygen fill port. When the tether lines develop slack, the net lift force is restrained by the oxygen fill port as shown in Figure 2.10. At this point the tether lines are disconnected from the fuel gas bubble freeing the winch trucks to take up new functions. Winch Truck No. 1 is connected to the triangular load plate and Winch Truck No. 2 is driven down to the far end of the payload train where it is connected. Truck #1 affords mobility and the winch on truck #1 allows the entire system to be raised to a sufficient height so that upon final release the payload will not contact the ground. With this arrangement the wind may blow in either parallel direction. The top end of the payload train is connected to its appropriate point on the triangular load plate with the load plate attached to the semi-circular swivel connection as described in the primary technique. Local control handling operations are completed at this point providing that all remote winch control function have been checked out. Fuel gas vehicles and personnel are evacuated from the immediate launch area and remote control operations can be initiated.

The remote control operation is similar to that described in the primary launch technique. The equipment arrangement shown in Figure 2.8 is applicable to both primary and alternate launch techniques and shows the balloon being remotely winched from the oxygen fill port area.

2.1.2.3 <u>AFCRL Launch System</u>

Another launch technique developed by AFCRL is shown schematically in Figure 2.11. The four basic steps involved in the launch procedure are 1) bubble layout and fuel gas fill, 2) oxygen inflation, 3) final release and 4) payload deployment. The advantages of this system are 1) it requires a minimal launch area due to the payload deployment system 2) it is independent of wind direction. The only potential disadvantage of the system is it has a more complex payload deployment system.

2.1.2.4 Major Launch and Handling Equipment Description

The winch trucks (General Motors Corporation, Chevrolet 1 Ton Model 31003) have a wheelbase of 133 inches, an overall length of 213-1/4 inches and a truck platform body 9 feet long. Gross vehicle weight rating is 10,000 lbs. with dual rear wheels. The platform body is large enough to accomodate the electric hoist, and the combined weights of the truck and hoist are adequate to restrain forces imposed during launch operations.

The selected hoists (Beebe Bros., Seattle, Washington, Model No. 6000 B20) have a line speed of 20 feet per minute (greater winch speeds are available if necessary), 6000 lbs. lift capacity, and a drum capacity of approximately 575 feet of 1/2 inch diameter nylon rope. They have disc type magnetic brakes integral with electrically reversible motors. The motors are remotely operated with push-button controls, and the magnetic brakes are normally engaged when the motor is switched off.

The nylon rope selected is 1/2 inch diameter, nonkinking, and has a safe working load of 1200 lbs. At 1200 lbs, the factor of safety is 5 to 1 for this rope. Nylon is exceptionally desirable because of its energy absorption and its shock loading characteristics.

The dynamometer (McMaster Carr, Chicago, Illinois) selected is normally used to determine strengths of chains and cables. The capacity of the dynamometer is from 0 - 500 lbs. in 5 lb. divisions and is used for determining net lift prior to releasing balloon and payload in the launching operation.

2.1.2.5 Launch Equipment Cost

Item	Description	Required Quantity	Cost
1	1 Ton Chevrolet Flat-Bed Truck	2	$ 4,868
2	Power Winch - Beebe	2	2,750
3	Nylon Rope 1/2 in. dia.	1200 ft.	334
4	Rope Clamps	18	48
5	Dynamometer	1	225
6	Pyrotechnic Cutters	4	175
		TOTAL	$ 8,400

2.1.3 Gas Loading Systems

The gas loading systems transfer the gases from the storage facilities to their respective compartments in the balloon. The gases (oxygen and fuel gas) will be injected into the balloon separately to reduce the possibility of a premature detonation of the combustible mixtures. The procedure will be to load the fuel gas first and to use the lift of the fuel gas to deploy the balloon from its shipping container. This will be a locally controlled operation with the launch crew in the immediate vicinity of the balloon. After the fuel gas loading operation is completed, the launch area will be evacuated of personnel and the oxygen then injected into the balloon by means of a remotely controlled system. The remaining launch operations would be remotely controlled.

The design of the gas handling system is dependent on the the size of tests that would be conducted. In the following discussion two representative cases will be considered. These are:

1. 86.6 foot diameter balloon, hydrogen-oxygen mixture ($O_2/H_2 = 0.75$), detonated at altitude of 50,000 ft. (1 ton)
2. 196 foot diameter balloon, methane-oxygen mixture ($O_2/CH_4 = 1.5$), detonated at altitude of 50,000 ft. (20 tons).

The volumes of gases required for each of these representative cases are:

Case No.	Volume of Fuel Gas, std. cu. ft.	Volume of Oxygen, std. cu. ft.
1	29,700	22,300
2	241,600	362,400

2.1.3.1 Fuel Gas Loading System

The technique used to inject the buoyant fuel gas into the balloon will essentially be the same as that used for conventional lift balloons. Flexible inflation ducts integral with the balloon will be used to transfer the fuel gas from the storage trailers to balloon. The upper polar duct would be used to initially inflate the gas bubble and to start the deployment of the balloon from the shipping container. After a small bubble has been formed and the balloon is deployed enough to expose the remaining inflation ducts, the polar duct may be disconnected from the gas supply units. The lateral ducts located lower down on the balloon are then connected to the fuel gas supply and the balance of the fuel gas is injected into the balloon. The number of inflation ducts used would depend on the desired inflation time for the test under consideration.

In all of the cases considered in this discussion the fuel gas would be delivered to the test site in a gaseous phase. Compressed-gas tube trailers with capacities up to approximately 112,000 SCF of hydrogen, 146,000 SCF of methane, or 149,000 SCF of oxygen are available for lease or purchase. For Case No. 2, two of these tube trailers would be used for delivery and storage of the methane at the test site. Tests requiring smaller quantities of gases would use tube trailers of correspondingly smaller capacity or in some instances both the fuel gas and oxygen could be transported with the same tube trailer (gases contained in separate cylinders and not mixed). A high pressure hose and plastic diffuser is used to transfer the gases from the tube trailer to the flexible balloon inflation ducts.

During the fuel gas inflation stage of the launch operation, the fuel gas tube trailers would be positioned in the launch area. (See Figure 2.9.) The tube trailers would be removed to safe position at the same time operating personnel are evacuated from the launch area. In tests where the same tube trailer is used to transport both the fuel gas and the oxygen, the trailers would be positioned at the remote oxygen loading station after leaving the immediate launch area.

The quantities of fuel gas injected into the balloons may be determined by several methods. Static pressure and temperature in the gas storage units may be monitored to establish the amount of gas delivered to the balloon. Another method would be to measure and totalize the gas flow to balloon with one of several types of gas flow rate meters. Gas flow rate meters which could be used are orifice meters, positive displacement meters, or turbine meters. There are commercially available instruments that use the meter output signals to compute the flow rate and totalize the flow volume. Another method would be to measure the lift force acting on the balloon and determine the volume of gas in the balloon.

2.1.3.2 Oxygen Loading System

The oxygen will be loaded into the balloon by means of a remotely controlled system. Because of safety consideration, the oxygen storage facilities will be located approximately 1000 feet from the launch area. The oxygen will be transferred from the storage units to balloon by means of a steel pipeline. (see Figure 2.12.) The oxygen will be injected into the balloon through an inflation valve located at the lower polar cap of the balloon. This valve will provide the interface between the balloon and the pipeline. The inflation valve must be capable of being remotely actuated since the launch area is cleared of all personnel during the oxygen loading phase of the launch operation. In addition to closing the valve remotely, it must also be disconnected from the pipeline by a remote operation to permit launching of the balloon.

A proposed valve design is shown in Figure 2.13. In this design, cartridge actuated devices are used to perform required functions. Cartridge actuated devices have the advantages of being reliable and requiring relatively small amounts of energy to activate them. The valve plates are held in the open position by means of the retaining fork. Both the valve plates and the retaining fork are spring loaded. To close the valve, the latch pin is activated which allows the retaining fork to retract and the valve plates are moved to the closed position by means of the spring force. The valve is disconnected from the pipeline by activating the cutters which sever the bolts fastening the valve to the pipeline. The valve assembly is mounted in the lower polar cap of the balloon by means of clamp rings.

The design of the pipe system for the oxygen transfer was based on the gas quantities which would be handled in the test represented by case 2. In order to obtain reasonable filling times, large flow rates will be required. A flow rate of 300,000 SCF per hour would result in oxygen filling time of approximately 86 minutes for the volume of oxygen required in the test. Assuming isothermal steady flow and an available pressure head of 30 psi, it was determined that 6 inch, schedule 40 pipe would provide the desired flow rate. This size of pipe would be more than adequate for tests requiring smaller volumes of oxygen.

The pipe system would be fabricated from flanged pipe headers in standard lengths. Two alternate pipe materials have been considered for the pipe system. These are Type A-53 steel and Type 316 stainless steel. The stainless steel pipe has the advantage of not requiring elaborate cleaning methods for the removal of any accumulated rust deposits after the system has been in the field for a period of time. However, the stainless steel construction is considerably more expensive than the A-53 steel construction (by a factor of approximately 7). It should be noted that the stainless steel construction may be more economical in the long run if a large number of tests (100) are planned.

Oxygen can be transported to the test site and stored there in either the gaseous or the liquid phase. In general the gaseous phase would be used for the smaller tests and the liquid phase used for the larger tests. In either case the oxygen would be transferred to the balloon in the gaseous phase.

Oxygen in the liquid phase has the advantages that smaller storage facilities are required and that for the same amount of gas the transportation charges are lower. For example, one million standard cubic feet of oxygen can be delivered in one railroad car. However, since the product will be transferred to the balloon in the gaseous phase, vaporizing equipment would be required on the test site. Steam-heated vaporizers with a nominal capacity up to 300,000 SCF per hour are available. A typical vaporizer installation to obtain a delivery rate of 300,000 SCF per hour without "freeze-up" would consist of a 300,000 SCF per hour vaporizer, a 100,000 SCF per hour vaporizer, a steam generator, and a liquid oxygen pump. The 100,000 SCF per hour vaporizer is added to insure against "freeze-up" which would occur by operating the 300,000 SCF per hour vaporizer alone. The quantity of oxygen delivered to the balloon would be determined by metering the oxygen in the liquid phase prior to vaporization.

For tests requiring smaller amounts of oxygen (as in case 1) the use of tube trailers to transport and store the oxygen in the gaseous phase would be more advantageous. In these cases the oxygen is transferred directly from the tube trailers through a pressure regulator and into the pipe line. The volume of oxygen delivered to the balloon would be determined in one of the ways described in 2.1.3.1.

2.1.3.3 Preliminary Cost Estimate

The exact cost of the gases and the gas loading system required for a particular test program will be dependent on such factors as the test site location, the frequency of tests and the total number of tests in the program.

Another factor in the determination of estimated costs is whether the launch facility is a permanent or temporary installation. A test site located at the White Sands Proving Grounds (see Section 2.2) will be assumed to provide a basis of the cost estimates.

Oxygen and hydrogen are both available in the gaseous phase at Amarillo, Texas, for $6.50 per thousand cubic feet, F.O.B. High capacity compressed-gas transporters may be leased in Amarillo at a rate of sixty cents per running mile with a standby charge of $140 per day after the first day. Amarillo to White Sands Proving Grounds is approximately a 700 mile round-trip so that the leasing charges for one transporter would be approximately $420 plus standby charges.

Methane is normally sold and distributed in the gaseous phase. High purity methane is relatively expensive, however, natural gas (90-95% methane) is available in most areas at a low cost. The exact chemical analysis of the natural gas used in a particular test should be established prior to performance of the test. The same compressed-gas transporters would be used to deliver the methane (natural gas) to the test site. The total cost for methane (natural gas) delivered to White Sands Proving Grounds is quoted at less than $10.00 per thousand cubic feet for large quantities. (This cost includes standby compressor, and other miscellaneous charges.) Natural gas may be purchased at the pipe line for approximately $0.83 per thousand cubic feet. The water content in natural gas is very low and does not require removal.* The natural gas would be tapped from the pipeline, compressed and then injected into the gas cylinders. A compressor may be rented for $140 per day.

In tests requiring smaller volumes of gases it would be possible to ship several gases with a single tube trailer. For example, in case No. 1, the required volumes of oxygen, and hydrogen could be transported in one tube trailer. Total costs for gases required for the tests would then be as follows:

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* DASA-01-68-C-0137; Underground Detonable Gas Explosions, Phase I, Engineering Design

ITEM	COST
29,700 SCF of hydrogen (Case No. 1) @ \$0.0065/SCF	\$ 194
22,300 SCF of oxygen (Case No. 1) @ \$0.0065/SCF	145
Gas transporter lease charge, 700 mi. @ \$0.60/mi	420
Gas transporter standby charge, 4 days @ \$140/day	560
Compressor lease charge, 1 day @ \$140/day	140
TOTAL	\$ 1,459

Liquid oxygen is available from Fontana, California, and the cost for a quantity such as required for case No. 2 delivered to White Sands Proving Grounds is quoted at \$1,890 for a full tanker load of 500,000 SCF. A truck tanker used for temporary storage will cost on the order of \$20 per hour. Portable containers are also available and may be more economical than the truck tanker for temporary storage. The cost of leasing a vaporizing installation to convert the liquid oxygen to the gaseous phase at a rate of 300,000 SCF per hour is quoted at \$150 per week plus a setup charge of \$2200. Also required for the vaporizer installation is a steam generator which is estimated to cost approximately \$150 per day for rent and operator plus approximately \$2000 for setup and transportation. The vaporizer installation used would have a nominal capacity of approximately 400,000 SCF per hour in order to provide the required delivery rate (300,000 SCF per hour) without "freeze-up". The cost of the gases and associated equipment required for a test represented by case No. 2 would then be:

ITEM	COST
241,600 SCF methane @ \$0.00083/SCF	\$ 200
(2) gas transporters, 700 mi. @ \$0.60/mi/unit	840
Standby charges, 4 days @ \$140/day/unit	1,120
Truck Tanker Standby Charges, 4 days @ \$480/day	1,920
362,400 SCF liquid oxygen delivered to test site	1,890
Vaporizer lease charge, 1 week @ \$150/week	150
Vaporizer setup charge	2,200
Steam generator lease charge, 4 days @ \$150/day	600
Steam generator setup and transportation	2,000
Compressor lease charge, 2 days @ \$140/day	280
TOTAL	\$11,200

The pipe line used to transfer the oxygen from the storage units to the balloon will be approximately 1000 feet of 6 inch diameter, schedule 40 steel pipe. The pipe is fabricated into standard length flanged headers to permit assembly of the pipe line in the field. The cost for the pipe line constructed from A-53 steel is quoted at $5,720 as compared to $42,900 for Type 316 stainless steel construction. Stainless steel has the advantage of eliminating problems due to corrosion in the field. However, for the difference in cost the A-53 steel pipe line can be disassembled and cleaned in the field, if necessary, after the pipe line has been in service for a period of time. Remaining items for the pipe line such as the diffuser section, pipe supports, field erection and transportation are estimated to cost on the order of $4000 total.

2.1.4 Instrument and Flight Control

This section of the study report is primarily concerned with the free field instrumentation, flight control components and techniques required to support the high altitude blast generation system. Free field instrumentation is required to define the characteristics of blast phenomena at various altitudes. Measurements are necessary to verify theoretical predictions and ground level experimental results. The flight control components are the command link, firing circuit, flight safety components and tracking components.

2.1.4.1 General Requirements

The requirements in balloon flights are significantly different from those normally encountered in other unmanned missile or aircraft instrumentation and control systems. Shock and vibration requirements are virtually nonexistent in balloon flights. In this case, however, shock due to the blast wave is a consideration, although the majority of the data can be obtained before the equipment encounters the shock wave. Normally the shock specification is established to cover that encountered in recovery impact. A value of 10g to 15g is normally used. It is recommended, however, that a value of 20g be selected based on previous experience in balloon instrumentation programs.

Temperature, humidity and altitude are the critical environment factors. The anticipated range of values for these parameters is given below:

Temperature:	-70°C to +50°C
Humidity:	0 - 90 percent RH
Altitude:	0 - 100,000 feet

Balloon location is also of importance, particularly at detonation in order to correlate predicted and actual free field blast effects. It is expected that altitude will be known to ± 200 feet.

Weight is an important factor since it dictates the minimum size of balloon which can be employed on any particular test. Weight should be held at a minimum. A weight of 600 pounds total payload less balloon and ballast has been selected as a maximum.

2.1.4.2 Free Field Instrumentation

Free field data may be obtained in many ways. However, for the high altitude blast generation system several restraints have limited the techniques that may be used. Primarily, the system selected should be in existence and made up of "off-the-shelf" components of proven reliability. This suggests that no approach requiring extensive development be considered.

The conventional techniques employed in data collection are: (1) to store data on-board; (2) telemeter data to the ground; or (3) a combination of both. Advantages exist in each of the techniques. However, for reasons presented in Section 2.1.4.2.2, Data System Specifications, the on-board data storage technique was selected.

2.1.4.2.1 Data Requirements

The data required to define the blast and shock environment is the pressure-time history at selected points between the surface of the balloon and a point about 200 feet distant. Since the blast wave for all practical purposes is spherical in geometry, it can be adequately described if measurements are made on a single radial line. The most convenient is one along the gravity vector. Over the range of altitudes and test conditions anticipated, the pressure will vary from a maximum of 200 psi at the balloon surface to about 1 psi at 200 feet away, the decay being similar to usual exponential decays. A minimum of 5 measurements are considered necessary over this distance. A greater number would, of course, enhance the reliability of the data acquisition system. The frequency response requirements depend on the local ambient pressure and shock front velocities. Based on an altitude range of 20,000 to 100,000 feet and a maximum shock front velocity of 5,000 fps, a response of 20 kHz is required to provide an overall accuracy on the order of 5 percent.

In addition to the pressure-time histories, detonation wave time-of-arrival measurements should be made within the balloon. The instrumentation to make this measurement should have a resolution of 5 microseconds. This assumes a detonation velocity on the order of 7,000 to 8,000 feet per second. Two or more measurements within the balloon are desirable.

All of the above measurements must be referable to an accurate time base. Additionally, meteorological data such as static pressure and ambient temperature at blast altitude are required.

The above data requirements are summarized below:

Measurements	No. of Channels	Specifications
Time of arrival	(2 points minimum)	5 μsec resolution
Pressure-time history	5-10 points (5 minimum)	200 to 1 psi; 20 kHz response
Ambient pressure	Multiplexed	0.1 to 15 psi; DC to 10 Hz
Ambient temperature	Multiplexed	-70°C to +50°C; DC to 10 Hz
Time-base reference	1	Time signal capable of resolving 5 μsec.

The above data requirements represent the minimum practical to obtain useful information. It would be desirable, particularly on early tests, to employ two pressure transducers at each location for improved reliability. On-board photographic coverage would be valuable as documentation of the event.

2.1.4.2.2 Data System Specifications

Due to the large amount of field testing taking place in this country, a method of standardizing procedures became a necessity. In 1948, a standard in the field of telemetry for guided missiles was established, commonly referred to as IRIG (Inter-Range Instrumentation Group) standard. Other standards were subsequently established and updated as the need arose. The obvious purpose of the standards is to insure interchangeability of hardware between ranges and test sites, provide common data formats and timing, and to establish practical accuracy and response characteristics for various modes of data handling. Conversely, having an accuracy and bandwidth requirement, the IRIG specification will indicate the practicality of using a given approach in the collection and processing of the data.

The significance of the IRIG specifications is obvious. The instrumentation requirements for the high altitude blast generation system are within the areas covered by the IRIG specifications. Therefore, to derive the benefits of previous experience, GARD recommends that the instrumentation system shall be IRIG compatible.

The two applicable approaches covered by IRIG specifications are telemetry and single carrier magnetic tape recording. For normal telemetry FM/FM proportional subcarriers, even with constant bandwidth "C" channels, the nominal frequency response is 1.5 kHz with 8 kHz a maximum available at increased noise susceptibility and therefore less accuracy capability. However, for direct record and single carrier FM, (operating at a tape speed of 60 ips in the intermediate band) the response in the direct record mode is 300 Hz to 250 kHz and in the FM mode the response is DC to 20 kHz. This band is the present standard of the industry and equipment is readily available complying to these specifications. In the direct record mode, amplitude accuracy is on the order of 5 to 10 percent of full scale with standard equipment. In the FM mode accuracies up to one percent of full scale are readily obtainable. For this reason telemetry for time-of-arrival data and pressure-time data has been eliminated from further consideration and it is recommended that magnetic tape recording be employed. Time-of-arrival data should be recorded on a direct record channel since high frequency response is required while amplitude accuracy is not important. All other data (excepting reference frequencies) should be recorded on FM channels where both response and amplitude accuracy are a requirement.

2.1.4.2.3 Survey of Existing Instrumentation Systems

A comprehensive survey was conducted of instrument systems which have been developed for the government. It would be desirable to utilize these systems if a cost savings could be realized. It must be remembered, however, that most of the systems have been hardened for nuclear environments or other specialized functions and therefore, are much more sophisticated than required for a high altitude blast generation system. The systems investigated and discussed herein are:

System	Development Agency
WETR II	BRL
Northrup System	HDOFL
EG & G	Sandia
Blue Rock	NOL
Banshee	NOL
Spindrift	NOL
DAQ-PAC	AFWL

WETR II - The Weapons Effects Test Recorder (WETR) is a general purpose magnetic tape recorder system for use in nuclear measurements. It is specifically designed to record during nuclear events. It is immune to neutron, gamma and EM radiation. This is accomplished by external shielding and low impedance balanced inputs. The unit, designed for bunker installation, is large and heavy and therefore not suitable for airborne applications employing balloons or rockets as the lifting vehicles.

The WETR has been developed and several units have been used in the field. Performance to the specification has not been completely proven. Therefore, the unit is undergoing product improvement development. The original design employs a tape transport operating at 120 inches per second. The newer units are using 150 inches per second to obtain the desired frequency response. The WETR concept is being employed in other developments such as the Northrup unit (described next) and AFWL underwater recording system. This unit is not recommended for the high altitude blast generation system.

Northrup System - The BRL hardened missile-borne recording system is presently in final development by the Northrup Aircraft Corporation. The system was designed for a high level radiation environment and utilizes vacuum tubes as the active elements.

The system is based upon a 14-channel magnetic tape transport having characteristics very similar to the WETR unit. A difference is that the transducers are supplied as part of the system.

As mentioned above the unit is still in the development stage. It employs about 900 vacuum tubes which limit the shock level without protection to about 15g and requires a large power supply. Being a nonstandard system, a large amount of ground support equipment is required including an 8-ton air conditioner for cooling on the ground. The unit is not recommended for the high altitude blast generation application.

Edgerton, Germeshauser and Grier Data Recording and Telemetry System (EG & G) - The EG & G system is a missile-borne instrumentation canister capable of tape recording and subsequently transmitting seven channels of data to a ground station. The data is recorded on a seven channel tape record/reproduce system. It then is sequentially reproduced, one tape channel at a time, and transmitted to a ground station via an S-band telemetry system. The combined systems have a bandwidth extending from dc to 250 kHz, and an instantaneous signal-to-noise ratio of 26 db per channel, ninety-nine percent of the time.

The entire system has been built into a 9-inch diameter canister capable of being borne aloft on any one of a family of 9-inch sounding rockets. Following data acquisition, the canister is separated from the spent booster and a drogue parachute is deployed in order to obtain the longest possible data transmission time.

The data is recorded on a seven channel magnetic tape record in FM format operating at 120 inches per second. A center frequency of 750 kHz is employed to provide the frequency response of DC to 250 kHz. Maximum data recording time is 11 seconds.

The EG & G unit is a record and telemeter system and is still in development to improve performance primarily with respect to environmental specification. For use on a high altitude blast generation system, extensive modification would be required and therefore is not recommended.

NOL Blue Rock System - The NOL Blue Rock instrumentation system is a self-contained 14-channel magnetic tape recording system capable of storing approximately one minute of continuous data. The missile borne unit is of hybrid vacuum tube, semiconductor design with semiconductors being used only in the least critical circuits. The system is complete with transducers, most of which are of NOL design.

On channels employing active sensors, the transducers form an integral part of the electronic units, i.e., the transducer, signal conditioning amplifier and record amplifier are matched and calibrated as a single unit commonly referred to as a bridge oscillator circuit. Frequency response is on the order of D.C. to 20 kHz.

The system lends itself to the high altitude blast requirements insofar as channel availability and frequency response requirements are concerned. The existing package layout is compatible with the high altitude blast requirements and the programmer could be modified to perform the required functions. Two problems do exist however. First, since the unit is in test and evaluation, the availability of this system is not definitely known. Second, as mentioned above the signal conditioning amplifiers are such that the transducer forms an integral part of the amplifier. Each amplifier must be matched to the individual transducer and the amplifier should be located in close proximity to the transducer. Program requirement of 100' to 200' distance of the transducers from the instrument minimizes the usefulness of these amplifiers. Also it is expected that piezoelectric transducers may be used. If this is the case, considerable development would be required.

Banshee - Project Banshee (Balloon and Nike-Scaled High-Explosive Experiments) employed several instrumentation canisters developed by the General Electric Company under the direction of the Naval Ordnance Laboratory (NOL).

The system which consisted of four instrument canisters and a control and instrument package, has been successfully proven in the Banshee program. Each canister contained various transducers and signal conditioning amplifiers. The magnetic tape recorder and programmer were located in the instrument package.

Although the Banshee instrumentation proved adequate particularly in the later tests, discussion with members of NOL have concluded with a recommendation that it not be used on the high altitude SLEDGE. GARD concurs with this recommendation. The system employed several nonstandard frequency channels some of which were multiplexed. This approach contributed to noise in the system making data reduction difficult. Also the costs to fabricate are moderately high.

Spindrift - Spindrift is a program presently in development at NOL. Detailed information is not available on size, weight and performance characteristics. The system employs Schaevitz-Bytrex pressure transducers and has a bandwidth capability of 0 - 5 kHz recording in FM analog mode on magnetic tape. NOL feels that this system can be incorporated in the high altitude SLEDGE. Considering the 20 kHz bandwidth requirement mentioned earlier, GARD does not feel that this system would provide adequate data accuracy.

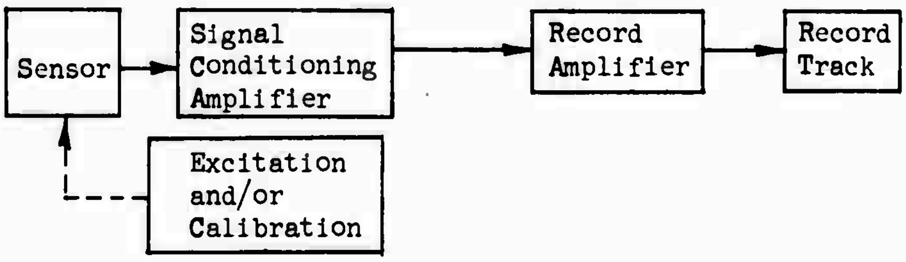
DAQ-PAC - DAQ-PAC is a complete self contained portable data acquisition system developed for the Air Force Weapons Laboratory by GARD. The unit is radiation hardened. It was developed for close-in, above ground nuclear testing. It is fully developed, has been tested and has met or exceeded every design specification. All units are plug-in modules allowing the choice of transducer types and analog recording formats. The DAQ-PAC is basically a two part system comprising: (1) preamplifier units providing excitation voltage for transducers, automatic calibration, bridge balance, bridge completion and balanced differential preamplifiers to provide adequate signal levels for recording; and (2) an analog magnetic tape recording system for recording in both direct and FM format per IRIG specification 106-66.

DAQ-PAC is directly applicable to the high altitude SLEDGE requirements. It is compatible with any of the transducers presently available or may become available in the near future. The weight is 275 pounds including an overpressure protection shell. The electronic section alone weighs 55 pounds when removed from the shell. However, features incorporated to withstand the nuclear environment has made the DAQ-PAC high in cost.

Of the instrumentation systems described only DAQ-PAC and the NOL Blue Rock units are adaptable to the high altitude blast generation system. The other systems are either in development, have limited frequency response capabilities or are not adaptable to balloon borne applications. Neither the DAQ-PAC or Blue Rock systems are recommended, however, due to the large costs involved in fabricating these systems.

2.1.4.2.4 Component Investigation

Several manufacturers supply components which can be readily assembled into a system for balloon-borne instrumentation. As mentioned previously, the advantages of complying with IRIG specifications are many; thus the components discussed will be IRIG compatible. The typical instrumentation channel is shown below:



The configuration shown above is oriented toward analog magnetic tape recording but can be applied to any type of storage media or format of storage depending upon the type of signal conditioning unit and storage amplifier employed.

The components available to implement the instrumentation are described in the following paragraphs. In each case many manufacturers were contacted for information but only those components which were deemed most applicable are discussed.

Sensor Investigation

Some 14 manufacturers of those contacted supply pressure sensors useable on the high altitude SLEDGE program. Many of these were eliminated due to low resonant frequency (low response) and/or the stringent temperature specification. Although the sensor may be packaged in a heated or thermally insulated package, transducers are available which can meet our requirements without special packaging. We have taken the latter approach and selected two manufacturers for further consideration: Kistler Instrument Corporation and Schaevitz Bytrex. The manufacturers specifications are given below:

Schaevitz Bytrex Model HF-100 (Piezoresistive)

Nat. Freq.	40 - 60 kHz
Lin. & Hysteresis	1%
Thermal Shift	0.01%
Thermal Sensitivity	0.01%
Shock	0.002%/g
Temp. Range (compensated)	55°C
Operable	-55 to +150°C

The Schaevitz Bytrex gage can be compensated over a range of 55°C at any operating temperature. Therefore, it is possible to obtain a gage compensated for a range of -55°C to + 0°C ambient operating temperature. Two disadvantages exist in the use of the Schaevitz gage: (1) the natural frequency is lower than desirable, particularly in low range pressure gages, and (2) a separate signal conditioning amplifier is required.

Kistler Piezotron Model 203L (Typical)

Range Full Scale	100 psi
Linear Overrange	1000 psi
Sensitivity at F.S.	10 ± .2 mv/psi
Resolution (noise)	.02 psi
Linearity Deviation	± 1% F.S.
Rise Time 0 to 90%	1 microsecond
Thermal Sensitivity Shift	+ .02%/°C
Acceleration Sensitivity	.002 psi/g
Output Impedance, Nominal	100 ohms
Temperature Range	-75 to + 120°C
Vibration 5 - 2000 cps	1000 g's peak

The major advantage of the Kistler gage is the built in signal conditioning amplifier which reduces the noise susceptibility when used with long signal lines. The major disadvantage is its susceptibility to transient thermo-pulses which could contribute to inaccurate pressure decay data.

Several shock tube tests were performed by GARD on the Kistler Piezotron Model 203L and the Schaevitz-Bytrex transducer Model HS-100. Early tests have shown that the Kistler gage is susceptible to transient temperature pulses. In working with the manufacturer it has been found that a coating can be placed on the gage face which will make it essentially immune to the thermal effect. Although the gage appears to be satisfactory in performance, actual dynamic calibration is difficult in our shock tube due to the ringing effect. As can be seen in Figure 2.14 both the Schaevitz-Bytrex and the Kistler gage exhibit pronounced ringing. The ringing is at a much higher frequency on the Kistler gage due to its higher response characteristics. It would be desirable on early tests, to use both transducers to determine which one would perform more satisfactorily.

GARD has performed extensive testing to derive a successful technique for detonation wave time-of-arrival data within the balloon. A breakwire approach was abandoned early since it was difficult to distinguish a distinct wire break from shunting by the ionized gases. On occasion a broken contact was reclosed by the detonation wave obscuring the original break data.

Most of the subsequent effort was oriented toward printed circuit gaps for measurement of the ionization front. These were very successful particularly with gas mixtures at atmospheric pressure. Reduced pressure tests performed at BRL showed that the signal was not as pronounced as signals at atmospheric pressure. In some tests a Schmitt trigger was used to generate a pulse from the signal as the wave passes each gap. This approach provides more readable data but affected the accuracy of the data. An analog recording of the raw data offers a better approach, but requires interpretation in data reduction. A modified printed circuit providing alternate positive and negative pulses is recommended to improve the definition of the wave front.

A typical sensor strip is shown in Figure 2.15. Sensors are located at 5 foot intervals along a 2 inch wide printed circuit strip. Even numbered sensors are excited by a positive voltage and odd sensors by a negative voltage. As the wave front passes the sensors, alternate positive and negative pulses are generated. This approach minimizes the problems of one signal masking the next signal due to a slow decay rate. The sensors would be excited with $\pm$ 3 volts to minimize the possibility of detonable gas ignition due to sensor excitation. The signals are summed as shown in Figure 2.15 and recorded on a direct record channel on which the fiducial signal can also be recorded.

Analysis of free field effects requires a knowledge of the meteorological environment at the blast altitude. This requires the measurement of ambient air pressure, temperature, and relative humidity. These parameters should be monitored over the following ranges:

1. Pressure-Altitude: to 10 mb (100,000 ft.)
2. Temperature: to -58°C
3. Humidity: 10% to 100%

The acquisition of meteorological data can be accomplished with conventional transducers, as part of the instrumentation system, recording temperature, pressure, and humidity. This approach offers several advantages. First, the data is recorded on the same tape as the blast data. Second, all or a portion of the data may be transmitted to the ground. Third, since the data rate is slow it can all be multiplexed on a single tape track. A typical multiplex system is shown in Figure 2.16. In the interest of economy, one instrumentation amplifier is used which includes built-in excitation voltage and calibration. All three sensors are energized in parallel from the excitation source and all outputs switched into a single amplifier by the multiplexer. With this approach each bridge circuit is selected to provide output signals of the same order of magnitude. This also lends itself to a common calibration scheme as shown in Figure 2.16. Data identification is accomplished by recognition of two open segments in the data stream.

As an attractive alternative, standard meteorological radiosondes are in every day use by both the Weather Bureau and the various military services. The radiosonde consists of a compact radio transmitter, complete with antenna and components for measuring pressure, temperature, and humidity, and a means for modulating the transmitter. Pressure is measured by means of the displacement of a contact arm mounted to an aneroid element. Temperature and humdity are measured by virtue of their effects on special variable resistance elements which control a blocking oscillator and modulate the carrier frequency over an audio range of 10 to 20 Hz. The pressure element also acts as a switch to alternately connect the temperature and humidity sensors in the circuit.

Radiosondes are available for operation at several transmission frequencies, including 72.2 MHz for shipboard use, 403 MHz for use with SCR-658 ground equipment, and the meterological data channel at 1680 MHz compatible with the AN/GMD-series rawin sets. All of the ground stations use a radiosonde recorder, such as the AN/TMQ-5, for data presentation.

Commercial radiosondes have nominal ranges of 1050 to 5 millibars for atmospheric pressure, temperature from + 50°C to -90°C, and 10 percent to 100 percent relative humidity. The overall probable error in pressure measurement of present units is:

± 1 mb at 1000 mb

± 3 mb at 500 mb

± 1.5 mb at 100 mb

± 1.5 mb at 10 mb (100,000 feet)

The overall probable temperature measurement error is about ± 0.5°C., and the probable humidity error is ± 2.5 percent.

Signal Conditioning Amplifiers

The signal conditioning amplifier performs the function of matching the transducer to the storage media through the record amplifier. In analog recording it is normally a straight voltage or current amplifier to raise the sensor signal to a high enough level to drive the record amplifier. The primary data, pressure-time, requires both low frequency and relatively high frequency response. These responses are best obtained from DC amplifiers. Many types of DC amplifiers are on the market for this purpose. Furthermore, many manufacturers provide amplifiers with associated excitation supply and automatic calibration capability. The latter type considered here are available from Honeywell, CEC, and Endevco. One major disadvantage of these units is that they operate from 115 volts 60 Hz power sources which are difficult to use in balloon testing. Two amplifiers more directly applicable to balloon instrumentation are DAQ-PAC DC amplifier Model 1062 and Genisco Technology Corporation Model 23-150 DC amplifier. Specifications of these amplifiers are given below:

DAQ-PAC Model 1062 Amplifier

Input	± 0.005 volts for ± 2.5 volts output
Response	DC to 20 kHz ± 0.3 db
Bridge Excitation	0 - 10 volts DC 1 watt
Regulation	± 0.05%

Genisco Model 23-150 Amplifier

Input	± 0.025 volts for ± 2.5 volts output
Response	DC to 20 kHz ± 0.5 db
Zero Drift	± 0.1% in 24 hours
Zero Drift (temperature)	2 uv/°F referred to input
Excitation Output Voltage	5 - 20 v. DC @ 45 ma.

A listing of these and various other amplifiers appears in Table 2.1.

Tape Recorders

The prime concern in the selection of a recorder is to obtain a small light weight unit which can perform in a field test environment. Although this study is concerned with a minimum requirement of six data channels plus a reference track, a 14 track recorder is recommended to allow for expansion. The added cost for the additional tracks is very small.

Single carrier FM recording is considered for all data except time-of-arrival which requires high frequency response. These data will be recorded on a direct record channel. All systems considered are IRIG and consist of all necessary record electronics and reference oscillators. Of the 27 manufacturers solicited, four have been selected as possible suppliers for the WABGS. A summary of these four appears in Table 2.2.

Additional Circuitry

In the makeup of an instrumentation system certain peripheral components are required to insure a logical sequence of operation and as an aid in data reduction. These include a programmer or sequence control device, reference signal generators and a method of providing a fiducial signal.

In most cases, unless one complete system meeting the requirements is available, the programmer and other related components are fabricated to meet the functional requirements. Therefore, no attempt was made to obtain an off-the-shelf components. The typical programmer sequence would be as follows:

T-5 minutes	-	Warm-up power on
T-6 seconds	-	Calibration cycle - all units on
T-1 second	-	Back-up signal - all units on; back-up release of calibration relays
T-0	-	Fiducial signal
T + 5 seconds	-	Post calibration cycle

In addition to the programmer, one track of the tape recorder should be allotted to a time reference for data reduction. Stability is the criterion for the reference oscillator for which 50 kHz is the recommended frequency as a monitor of tape speed variations.

Flutter compensation is required and can be obtained by recording a 108 kHz signal on one track. Upon reproduction an FM reproduce amplifier using this signal, generates an error signal for data compensation. Compensation can be accomplished during data reduction. At large data processing facilities the flutter signal can be applied directly to the data reproduce amplifier for automatic compensation during playback of the magnetic tape.

Power Subsystem

As in any instrumentation scheme, electrical energy is required to power the various components of the system. This summary of energy sources indicates that the power requirements for the high altitude blast generation system is well within the capability of chemical batteries.

Electrochemical batteries for Aerospace applications can be classified in one of two ways:

1. Primary batteries, which can be stored in a charged condition or activated by filling with electrolyte immediately prior to use, and are employed for short term or "one shot" application.
2. Secondary or storage batteries, which can be recharged from a source of electrical energy and are subjected to repeated charge and discharge.

Choice of one of the two types is, of course, based primarily on mission duration and/or necessity for recharging. The most critical requirement of the blast simulation program is the successful acquisition of free field data. Minimization of the probability of battery failure through one-time use, plus simplification of auxiliary circuitry by eliminating charge control, are very desirable. Therefore, on the basis of potential reliability, a primary battery system is preferred.

Sealed nickel-cadmium batteries are at present the only type of electrochemical power source which have been extensively used in aerospace applications. To date, more than 75 percent of NASA's satellite programs have utilized Ni/Cd secondary batteries. Aside from a high confidence level, the major advantage of Ni/Cd batteries is their long cycle life. They have the capacity for tens of thousands of recharge cycles. On the other hand, however, their energy density is very low. The energy density is more than a few watt-hours per pound when control circuitry and packaging are taken into account. Although discharge capacity is degraded at low temperatures, Ni/Cd cells are the least sensitive of the three types that are discussed herein.

The silver-zinc battery offers the highest energy density of any primary battery system commercially available; it can also be used as a secondary or storage battery over a limited number of cycles with a corresponding reduction in energy density. This battery has excellent reliability, high energy per unit volume, and can be discharged at very high rates with good voltage regulation. Low temperature performance, however, is quite poor. Ag/Zn Battery systems have been used extensively in missile and weapons applications requiring high capacity primary power coupled with good environmental tolerance.

The silver-cadmium battery is a relatively new development, having seen limited application in aerospace systems. It offers a compromise between the long life and low energy density of the nickel-cadmium cell and the high-capacity, low-cycle life of the silver-zinc battery. In addition, it possesses certain electrical characteristics which simplify power control circuitry in secondary battery systems. The Ag/Cd cell also suffers from degraded performance at low temperatures.

It is recommended that nickel-cadmium batteries be employed as the primary power source. In tests involving low yields at high altitudes where weight is a predominant factor silver-zinc cells should be employed. In the interest of reliability individual battery packs should be employed to the greatest extent, recognizing, however, that a failure of the main battery pack would result in a complete loss of data.

2.1.4.2.5 Summary

As a minimum, the following data must be recorded to define the characteristics of the blast phenomena at various altitudes:

1.	Shock wave pressure-time history	5 points
2.	Detonation wave time of arrival	2 points minimum
3.	Ambient pressure, temperature, and relative humidity.	

It is recommended that the data be stored on a 14 track magnetic tape recorder complying with the IRIG specifications for operation at 60 inches per second in the intermediate frequency band. The recommended channel allocation follows:

1.	Pressure time history	-	5 channels FM record dc to 20 kHz
2.	Time of arrival	-	1 channel direct record 300 Hz to 250 kHz
3.	Ambient pressure Ambient temperature Payload temperature	-	1 channel - FM record multiplex input DC to 20 kHz
4.	50 kHz reference	-	1 channel
5.	108 kHz flutter reference	-	1 channel
6.	Spare	-	5 channels - FM record DC to 20 kHz.

None of the existing government sponsored systems are recommended primarily due to cost. The recommended recording system is a Genisco Tape system Model 10-110. Transducers, preamplifiers, a programmer and battery must be added to the Genisco System. The recommendations for these items are given below:

Transducers

Press.-Time - Kistler Piezotron Model 203 L

alternate Schevitz Bytrex H.S. Series

Time of arrival - printed circuit per Section 2.4.1.2

Temperature - thermistor

Ambient pressure - CEC Model 4-326

Preamplifier (if required)

Genisco model 23-150-1

Programmer

Fabricated per Section 2.1.4 2.4.

Battery

Nickel Cadmium

The complete system is shown in Figure 2.17.

Meteorological data should be obtained by carrying a radiosonde aboard the flight train. It is recommended that the same data be recorded on one track of the tape recorder along with the instrumentation package temperature. On the early flights it is recommended that a camera be carried to photograph the event.

2.1.4.3 Flight Control

The primary link in control of the balloon is the command receiver located on the balloon package and the command transmitter located at a ground control site. All ground commands are transmitted via this link. Multiple commands are necessary with six being the minimum considered practical. These are: payload cutdown; ballast drop; instrumentation warmup; normal detonation; backup detonation; and emergency detonation.

In addition, on-board backup safety controls are also desirable. Again as a minimum the following are desireable: Low Altitude Termination - if the balloon descends below 5,000 ft detonation is automatic; High Altitude

Termination - upon clearing the detonation altitude and detonation fails the flight train is cut loose; High Altitude Detonation - detonation upon clearing normal detonation altitude; Time Detonation - normal detonation based upon flight time Emergency Timed Detonation - timed detonation upon failing to reach altitude in prescribed time interval; Emergency Timed Termination - timed payload cutdown upon failing to reach altitude before specified time.

Telemetry is not a necessity but offers a return link from the balloon to the ground. Unless altitude is to be determined by tracking equipment, ambient pressure data or altitude should be sent to the ground. If a telemetry link is provided, it is a simple matter to also verify receipt of commands transmitted to the balloon. Also, if altitude data is transmitted to the ground, the main purpose of the tracking equipment would be reduced to monitoring balloon location for safety and recovery. Therefore, the accuracy that is required of the tracking equipment could be reduced.

2.1.4.3.1 Command Control System

The command control system provides the complete control of the balloon flight from launch to recovery. A functional block diagram of the typical system is shown in Figure 2.16. The essential elements are the command receiver, decoder which provides contact closures for each of the functions as transmitted to the balloon, the aneroid pressure switches which are used as passive safety devices in case transmission is lost to the balloon, and the mechanical timers which time the flight from launch to insure clearance to altitudes and detonation within the proper time limits. The command receiver and selector operating together and utilizing four properly time sequenced tones out of a total of seven available tones, allows the selection and eventual energizing of any one of nine available channels. The receiver requires two tones out of three available in order to activate one of three channels. This channel output, together with a third tone chosen from an additional three available tones, goes to the selector, and selects one of nine possible channels. A fourth tone, the seventh available tone, to the selector is necessary in order to energize the finally selected channel. This combination of tones plus time provides the degree of security necessary to insure against spurious signals activating a critical command channel.

Shown on Figure 2.18 are typical arrangements for the relay and switch closures to provide the proper functions. In the normal operating sequence a signal would be sent on channel 3 for instrumentation warmup approximately five minutes before detonation. This signal through relay closure K3 would turn on the instrumentation. Approximately six seconds before detonation, a signal would be sent up on channel 5 causing a closure of contact K5 to initial the normal detonation program In the instrumentation program six seconds would be required for calibration, after which a signal would be transmitted to the firing circuit to detonate the balloon. Depending on the mode of operation, the calibration sequence and detonation can be initiated through S3 or S4. If the procedure is to detonate the balloon as it passes through detonation altitude, an aneroid switch will close S3 upon obtaining that altitude, and initiate the instrumentation cycle. A time detonation would use the same procedure, however, S4 would initiate the cycle. Channel 6 is added as a backup. In case of failure to detonate at the proper time, a signal can be set up on channel 6 to close K6, initiating the instrumentation and energizing the firing circuit. Emergency detonation can take place through energizing K4 on channel 4 or S5 from the emergency-time-detonation circuit.

At any time during the flight, ballast may be dumped by energizing channel 1, closing relay contact K1. Ballast is also dumped on a normal detonation by a signal from the firing circuit through a two second delay. If an emergency exists where by the balloon cannot be safely detonated, the payload may be cut loose through any one of several means. The payload can be cut down by transmitting the signal on channel 2, or from the high altitude termination aneroid, or from the emergency time termination through S6.

All the components to implement the command control system are readily available and relatively inexpensive with exception of the command receiver and decoder. A search was made, therefore, for a command receiver, decoder and transmitter system for use on the program. Three such units appear in Table 2.3. Another attractive unit was developed by the Zenith Radio Corporation for the Air Force Cambridge Research Laboratories. This unit has a capability of nine channels operating on a two tone transmitted signal. Unfortunately, Zenith only provides the receiver and decoder; no transmitter is available for use with this sytem. The tone generator and transmitter were developed by AFCRL as an "in-house" project. This system has proven reliable on the Banshee and other balloon programs in which AFCRL has participated. This makes it very desirable for use on the high altitude SLEDGE program.

2.1.4.3.2 Detonation Circuits

The detonation (or firing) circuit ignites the explosive gas mixture upon receipt of a proper firing signal. A typical circuit can be seen in Figure 2.19 The explosive gas mixture is ignited by a blasting cap which is actuated by an electrical signal derived from a relay closure. Two completely independent circuits are employed to add redundancy to the system as a safety factor to insure detonation As can be seen in the figure, the two firing relays K1 and K2 can be energized from any one of three signals. In a normal firing sequence, a signal is sent from the instrumentation program immediately following the calibration cycle. In case of failure of the instrumentation program, a backup firing signal is available. This signal is applied to a one second pyrotechnic delay circuit. The one second is used to allow the instrumentation tape recorder to get up to speed before detonation of the gases. If the occasion should arise that the balloon be detonated in an emergency condition, a signal is obtained from either the aneroid pressure switch or the backup timer.

The wiring to the blasting cap is rather conventional with a twisted pair of leads leading from a pair of C type contacts up to the blasting cap. In the normally de-energized position of the relays, the blasting cap is shorted out by one leg of the relay contacts to keep the balloon and blasting cap at the same potential. When the relay is energized the contact moves to apply battery power to the blasting cap. Each blasting cap is operated from a completely independent circuit and each has its own battery supply for firing the cap. Sixteen D size alkaline batteries are used to detonate each cap. Relay contact K1B are used to blow a small fuse for verification of receipt of the firing signal. The extra contacts on the relay K2 are used to dump ballast after the completion of the balloon detonation

The event or fiducial marker is obtained by a twisted pair of leads wrapped on the blasting cap The leads are terminated in the time-of-arrival printed circuit strip. The signal is recorded along with the time-of-arrival data on the same track

A standard electric No. 8 blasting cap has been used on previous experiments. This cap has proven satisfactory for high ambient pressure tests. However, at reduced ambient pressures a booster was added to insure detonation of the gases. The expected firing time is about three milliseconds from activation of the relay contact to detonation of the cap.

2.1.4.4 Telemetry System

Altitude can be determined more accurately on board the balloon. Since pressure (altitude) is a slowly changing parameter, very little bandwidth is required. Therefore, pressure, temperature and a number of other low frequency functions can be transmitted on one information channel to ground.

The same channel can be used to verify receipt of command signals. As with the recording system, an IRIG compatible system is recommended. AFCRL has a command system available with a return communication link which can transmit pressure data, a flight identification code and a CW signal used for tracking.

In lieu of a telemetry system, a radiosonde may be used as described in section 2.1.4.2. Although it lacks the capability of adding any additional information, it is a relatively inexpensive device and may be readily incorporated into the system. It has the added advantage in that it may be used for obtaining tracking data when used with the Rawin system as will be described.

2.1.4.4.1 Tracking Requirements

As stated previously for correlation of predicted and actual blast effects the altitude of the balloon system should be known to within $\pm$ 200 feet. The selection of a tracking system depends also on the target to be tracked. Depending on how information is provided to the tracker the target is termed active or passive. A passive target merely acts as a reflector for ground-originated tracking signals, while an active target emits intelligence either in the form of answering signals to an interrogation from the ground station, or as beacon signals generated by the normal operation of the target.

The next few paragraphs discuss the operation and performance characteristics of several devices or systems potentially useable for high altitude balloon tracking. This discussion is followed by a summary of the various approaches and consideration of available tracking equipment at several instrumented missile or balloon test ranges.

2.1.4.4.2 Radar Tracking Systems

The primary function of an instrumentation radar is to provide tracking information for determining the flight path or trajectory of an airborne vehicle. Two modes of tracking are employed by range radars: skin tracking and beacon tracking. In skin tracking, the radar output pulse signal is reflected from the target and picked up by the sending/receiving antenna of the radar. The maximum range of this technique is limited by the radar cross-section of the target. It has the advantage, however, of not requiring an airborne transponder. In beacon tracking, the radar signal is used to interrogate an airborne beacon, which sends back a pulse to the ground radar at a slightly different frequency from the transmitted pulse. This concept greatly increases the accuracy of the radar and often extends the useable range by a factor of four.

The AN/FPS-16 radar is a high precision C-band monopulse tracking radar designed specifically for missile range instrumentation. It has the capability of automatically following a moving target and providing precise, real-time digital information on azimuth, elevation, and slant range. The FPS-16 can operate in either the skin or beacon track modes. It will skin track a one square meter target to a range of 200 miles; beacon tracking range for standard configurations is approximately 600 miles. Nominal instrument accuracy of the FPS-16 is $\pm$ 5 to 15 yards in range, and $\pm$ 0.2 to 0.3 mil in azimuth and elevation.

The usual FPS-16 installation will provide elevation coverage down to -10°. Data, however, are generally not reliable below + 3°, since multipath transmission and ground effects can introduce inaccuracies. This problem can be eliminated by tying the radar into an optical director, boresight camera, or other visual tracking device.

Although the FPS-16 is available at most instrumented test ranges, it is evident that its potential for use with a semi-transportable blast simulation facility is limited. However, a multi-trailer mobile version, known as the AN/MPS-25, has been developed and is available in limited numbers at most of the more well equipped test sites, such as White Sands Missile Range, New Mexico.

Range radars with more limited availability can provide tracking accuracies ranging from ± 25 yards in range and ± 1 mil in angle for the AN/MPQ-12 and AN/MPQ-18 (modified SCR-584) S-band tracking radars, to ± 2 yards in range and ± 0.2 mil in angle for the TRADEX (Tracking Resolution and Discrimination Experiments) system on the Pacific Missile Range at Kwajalein Atoll in the Marshall Islands.

2.1.4.4.3 Continuous-Wave Tracking Systems

Continuous-wave (CW) tracking systems provide high accuracy data on vehicle position during flight. Without exception, these systems require the use of an airborne transponder or continuous-wave signal source, such as a telemetry RF carrier, to determine vehicle position. The principal advantage of CW tracking systems is that they can operate at long ranges with much greater precision than other radars. On the other hand, closely aligned fixed ground stations are usually required, and reduction and presentation of position information may pose data handling difficulties.

The DOVAP (Doppler Velocity and Position) system consists of a ground reference transmitter, a frequency doubling airborne transponder, and a number of remote ground receivers where the reference and return frequencies are compared and the Doppler frequency extracted and relayed to a centrally located data processing facility. Typical transmitter and transponder frequencies are 36.9 and 73.8 MHz, respectively. Position accuracies to ± 0.4 feet can be attained under proper operating conditions using a large number of DOVAP receiver stations.

2.1.4.4.4 Optical Trackers

Included in the optical systems of tracking instrumentation are theodolites, telescopes, ballistic cameras, and several other types of modified cameras. Because of the relatively low speed requirement for a balloon tracking, this discussion will be limited to tracking telescopes, low-speed cameras, and theodolites. Of these, only the theodolite is truly a tracking device. Telescopes with integral cameras and medium to long range camera systems are used almost exclusively for acquisition of altitude, ascent rate, and events data only.

The basic theodolite instrument has been used for years as a surveying device. Manually operated theodolites can provide azimuth and elevation data for low altitude balloons, but positional accuracy is quite limited.

The cinetheodolite (also known as phototheodolite) is a specially designed device for determining test vehicle trajectories. Two or more theodolites, placed at known distances from each other, measure and record on film the azimuth and elevation angles to the target. The space position of the target can then be computed from the base lengths and angle data. Time synchronization is usually provided by electrical pulses from a central timing station.

Position data accuracy of a cinetheodolite tracking system varies from $\pm$ 2 to 5 feet for altitudes up to 25,000 feet, $\pm$ 10 feet from 25,000 to 50,000 feet, and $\pm$ 20 feet from 50,000 to 60,000 feet. Accuracy deteriorates rapidly when the elevation angle exceed 70 degrees. Measurement of position data above 60,000 feet are difficult, if not impossible, with currently available cinetheodolites.

Optical tracking is limited to daytime operation under relatively cloudless conditions. Nighttime use requires an airborne light source or optical beacon. Further, some form of geometric pattern or target on the balloon system may be required to assist in daytime tracking at high altitudes.

Although the cinetheodolite possesses limited range and elevation capability, it represents an extremely useful low altitude element in an overall tracking system configuration.

2.1.4.4.5 Radio Direction Finding Systems

The primary function of a radio direction finder (RDF) is to determine the azimuth and elevation angles to a radio signal source. This is accomplished using a sensitive receiver and highly directional antenna; angle bearings to the target are read off the calibrated antenna mount. As applied to airborne targets, the major disadvantage of an RDF system is the necessity for an on-board signal source or beacon. In addition, angular accuracy is somewhat lower than for radar tracking systems.

There is, however, one fact which makes RDF tracking attractive; a meteorological data acquisition function must be incorporated in the free field instrumentation system. As discussed previously, this is already accomplished using a standard 1680 mHz radiosonde. Thus, the RDF requirement for on-board radio signal source is satisfied. Further, the standard military ground equipment for reception, recording, and display of radiosonde data, the AN/GMD-series Rawin Set, is in fact a radio direction finder since azimuth and elevation information is provided. With the use of a transponder radiosonde and the addition of a ranging adjunct to the Rawin Set, the RDF becomes a true tracking system which can provide position data for high altitude balloon experiments.

The AN/GMD-1 Rawin Set is a transportable receiving type radio direction finder specifically designed to automatically track a balloon-borne radiosonde transmitter. Used in conjunction with an AN/AMT-4 radiosonde (or equivalent), AN/TMQ-5 radiosonde recorder, or AN/FMQ-1 or AN/FMQ-2 radiosonde receptor, the resulting rawinsonde system provides atmospheric pressure, temperature, and humidity data, as well as recordings of time versus azimuth and elevation of the ascending balloon. The standard Rawin Set antenna is a single dipole with conical scanning and a seven foot parabolic reflector.

The Rawin Set automatically tracks the balloon-borne 1680 mHz transmitter to altitudes of 100,000 feet or more, and to horizontal distances of about 125 miles. Azimuth and elevation angles versus time are printed out by the Rawin Set control recorder. A block diagram of this rawinsonde system is shown in Figure 2.20.

The AN/GMD-2 Rawin Set is identical to the AN/GMD-1 with the addition of a ranging capability. This, of course,requires the use of a transponder-type radiosonde. Range information is obtained by measuring the phase difference between the transmitted and received range signal. A 74.94 kHz sine wave which is generated in the GMD-2 ranging attachment amplitude modulates a 403 mHz ground-based transmitter which is part of the Rawin Set. This signal is picked up by the 403 mHz receiver in the transponder where it is detected, amplified and used to frequency modulate the standard 1680 mHz (meterological data) carrier at 74.94 kHz. The 1680 mHz FM signal is received and demodulated by the FMD receiver. The incoming 74.94 kHz signal is compared with the signal generated at the ground set; the phase difference between them is a measure of slant range.

The angular tracking accuracy of the AN/GMD-1 and AN/GMD-2 Rawin Sets is $\pm$ 0.05°. This is the maximum error between 10° and 60° elevation; accuracy degrades at higher or lower elevations. The range accuracy of the AN/GMD-2 is $\pm$ 25 yards or 0.25 percent of the slant range, whichever is greater.

The WBRT 60 (Weather Bureau Radiotheodolite; Servo Corp. of America, Model 4000) is a commercial modification of the AN/GMD-series Rawin Set which employs a larger antenna and special design modifications to provide increased angular resolution and accuracy ($\pm$ 0.03°RMS) at the expense of decreased transportability. Both the GMD-1 and the GMD-2 can be assembled or dismantled by two trained persons in less than one hour. The equipment can easily be transported in a standard 1-1/2 ton ordnance trailer. Being originally meant for field use, the GMD is easy to set up, requiring a minimum of siting and adjustment. The WBRT 60, on the other hand, is specifically intended as a fixed semi-permanent installation requiring hard-mounting and protection of the antenna and pedestal.

Of special importance to the selection of a tracking system is availability of ground equipment at GFE. The AN/GMD-series Rawin Set has been in the military inventory for almost ten years and should be easily obtainable as GFE for the high altitude blast generation program.

The entire spectrum of tracking systems is summarized in Table 2.4. This represents most of the more common systems currently available or in use. The major parameters to be considered in selecting the optimum tracking approach are: Performance (angular and range accuracy); cost of purchase or use; availability as GFE; compatability with free field instrumentation system; and transportability.

2.1.4.4.6 Summary

The flight control is necessary to accomplish a programmed flight plan and provide flight safety in the conduction of the test. It is recommended that the AFCRL command system be used in its entirety. The advantages are that the system has been proven in actual field tests and that the command transmitter-receiver has been approved by the White Sands Range Safety officers as being acceptable for use on the range. Tracking in this approach is by existing range radar equipment employing beacon identification. A beacon is also employed for tracking by the recovery vehicle.

The AFCRL system also employs a Radiosonde. The unit is part of the payload and provider of both tracking and meteorological data.

2.1.4.5 Flight Train and Package

The proposed flight train is shown in Figure 2.21. It consists of an instrumentation train, the command control and recording package. It is recommended that the instrumentation train be made up of 1/4 inch steel cable approximately 300 feet long. The pressure transducers would be located along the upper 200 feet of this line (with shock absorbers connecting them to the cable), spaced at predetermined intervals to provide meaningful data. At the upper portion of the line would be the connector of the time of arrival gage (located inside the balloon) and the abort cutter which would cut the train loose in case of an emergency termination of the flight. The transducers would be located in streamlined housings mounted directly to the line.

The instrumentation package design is typical of that used in balloon-borne experiments. The package should be fabricated in the form of a box framework using aluminum angles as the main structural components. The size of the box will vary depending on the type of components which will be carried. It is expected that the framework would be approximately 18 inches x 18 inches x 32 inches.

The framework will be lined with styrofoam to provide thermal insulation. A 5 inch thickness of styrofoam is required to limit the internal temperature drop to 40°F from an initial level of 75°F when subjected to an external ambient of -65°F for ten hours. The thickness is based on an internal mass of 180 pounds and no internal heat being generated. Therefore, a more than adequate safety factor exists to account for heat losses due to imperfections in the insulation. Since the internal equipment can operate at much lower temperatures than specified, the package should easily provide a suitable thermal requirement.

At each station or point of measurement, a pressure transducer mount (see Figure 2.22) will be clamped to the load line in such a manner as to provide a minimum of disturbance to the air shock wave.

2.1.4.6 Recommended Systems

The Genisco Technology Model 10-110, assembled into an IRIG compatible system with record electronics, reference oscillator and flutter compensation channel is recommended for the recording of data. To obtain pressure-time histories, the Schaevitz Bytrex pressure transducer is suggested along with the Genisco DC amplifier to provide signal amplification to drive the recorder amplifiers. An alternate is the Kistler pressure transducer which would not require DC amplifiers. Although redundant, a combination Kistler-Schaevitz system may be considered initially to compare the two types in the same environment. The respective transducer system costs would be $37,000, $33,500 and $40,750 including Genisco equipment.

A Radiosonde ($225) is recommended to obtain meteorological data. The radiosonde should be compatible with the AN/GMD-1 Rawinsonde system (GFE). With this approach, additional tracking is not required. However, if the program is to be conducted on a fully instrumented test range advantage should be taken of available radar tracking systems.

Additional instrumentation system suggestions are: a three channel multiplexer for recording ambient pressure and temperature along with the instrumentation package temperature ($1600); a fiducial generator ($120); a programmer calibration generator ($800); and nickel-cadmium batteries ($600).

The AFCRL command and control system is recommended at an estimated cost of $8000. Ground station component costs would be an additional $3000. Additional items and costs are: line cutter system; firing system ballast dump system; and instrumentation train and package all for a total cost of $3700. The cost of personnel and equipment to support the instrumentation and command systems is estimated at: $800/day for the FPS-16; $400/day for recovery chase vehicles; $500 for a communications net and $150/man-day for nonbased personnel (4 nominal).

2.1.5 Recovery System

2.1.5.1 Introduction

Recovery of instrumentation packages from high altitude balloon experiments entails the use of recovery systems which are both reliable and add very little weight penalty to the overall payload. There are in existence a number of recovery systems which can conceivably be adapted to perform the recovery task.

The idealized recovery system (aerodynamic decelerator) should have the characteristics of minimum deployment shock, minimum final descent or impact rate, maximum aerodynamic stability, minimum weight, and a high degree of reliability in the particular mission environment. Obviously, it can be seen that the foregoing characteristics must be optimized in each detail, to meet desired performance prescribed by the mission envelope.

The mission envelope, simply stated, calls for local and remote operations to accomplish balloon filling and balloon/payload launch handling. The balloon and its payload are then separated from all ground restraints, after final weigh-off readings have been taken, and the ascent to altitude commences. Gases contained in the separated fuel and oxidizer cells of the tandem shaped balloon are allowed to intermix upon disreefing. Upon detonation of the explosive gases contained in the balloon, the payload instrumentation/recovery system enter a state of free fall. It is at this instant that the recovery system senses dynamic pressure in its downward travel and deploys the parachute which in turn inflates to its projected design diameter. The descending parachute with the attached instrumentation package will encounter increasingly denser atmosphere causing it to continually decelerate until the design impact equilibrium velocity has been achieved at touchdown. The design impact equilibrium velocity will vary slightly because it is calculated on the basis of standard atmospheric density at sea-level.

2.1.5.2 Recovery System Types

The recovery system to be installed as an integral part of the payload train must be compatible with the design features thereon and not detract inordinately from the lifting performance of the buoyant balloon. It should also be adaptable in configuration so that it can be easily installed in the payload train which is suspended beneath the balloon while in flight. The recovery system should not interrupt the structural integrity of the continuous support line which runs from the instrumentation package to the balloon load connector plate.

Recovery system types which have been considered under this program are the parachute, the paraloon, the paravulcoon, the Rogallo-wing, rotor systems and the torroidal balloon. Each of these systems have been used successfully in regard to their particular performance capabilities and uniqueness of application, with the exception of the torroidal balloon.

The torroidal balloon was developed by GARD for the purpose of landing ground penetrometer instrumentation on the lunar surface, under NASA contract NAS-9-3731. This device could conceivably be adapted to the payload recovery operation, however it would require pneumatic inflation soon after detonation of the explosive gas filled balloon. This would require either a sensing element or timing mechanism to trigger a gas pressurized vessel to inflate the torroid. The inflated torroid is then expected to drift to the surface and act as a pneumatic cushion on ground impact or, in the case of a water landing, an impact cushion and flotation device. Models of the torroidal balloon have been constructed, but to date, no actual air drop or full scale tests have been carried out to thoroughly qualify this device in the recovery application.

Rotor type recovery systems have been advanced to a point where they are indeed successful and quite reliable. A highly desirable feature of the rotor system is that it does not undergo high values of opening shock when the rotor blades are deployed. Essentially it is meant to be a high initial velocity low opening shock recovery device with potential application in the area of manned space capsule deceleration upon atmospheric reentry. There would however be the problem of possible payload line fouling of the rotor system if it were to be used in the instrumentation recovery scheme.

The Rogallo-wing is basically a gliding device with a rather high L/D (lift to drag) ratio. It too has been proposed as a potential device for controlled space capsule reentry and landing. This device would be comparatively inexpensive to manufacture depending upon the degree of sophistication desired. It presents the disadvantage of extensive ground search recovery of the instrumentation package. In addition, the Rogallo-wing requires a fairly stable location of the suspended load center-of-gravity (C.G.) beneath the lifting surface to accomplish stability in the pitch axis of rotation. This constriction of c.g. location with a freely swinging pendular load makes pitch stability a questionable proposition with possible wing stall resulting from too great an angle of attack. In addition to the pitch stability problem, the encumbrance of mating the Rogallo-wing to the payload train would be rather unwieldly, especially when attempting the remote launch phase. Ground damage could possibly occur, disabling the recovery aspect of the experiment.

The paravulcoon attempts to combine the features of a parachute and a hot air balloon. It requires ignition of a heat source to warm the entrapped air in order to provide a degree of buoyancy during descent. The paravulcoon would be difficult to control remotely, due to required regulation of the heat source in order to achieve a controlled descent rate, which is the prime feature of this device. Its application to the recovery of balloon-borne payloads appears to be impractical.

The paraloon which is also referred to as a ballute or spherical decelerator is an inflated balloon which is girdled by an inflatable torroid in the region of its equator. The inflatable torroid in some configurations is replaced with small scallops or parachute gores. It was developed to perform under supersonic air flow conditions and to act as a flotation measure for touch-down at sea. Final touch-down velocities using the paraloon, are too high for consideration of its use in high altitude balloon instrumentation package recovery.

The parachute is next in line of consideration. To date, there have been many developments or modifications of the parachute to meet certain behavioral characteristics of performance. Recovery of the instrumentation package from a gas detonation environment at altitude with the constrictions of low weight addition to the payload, adaptability to form an integral part of the payload train, ease of manipulation during launch, and ability to achieve soft landing velocities are attainable with the parachute. Therefore the parachute is recommended as a recovery system type.

2.1.5.3 Selection of Parachute Recovery System

In surveying the spectrum of typical performance characteristics of parachute canopy configurations, one particular type appears quite suitable for the instrumentation package recovery task. This canopy is the 10 percent extended skirt flat circular type. It is normally used for both personnel and cargo drop applications, in addition to final stage recovery of aerospace vehicles. Nominal drag coefficient (C_{D_o}) applicable to this canopy type range from a value of C_{Do} = 0.70 to 0.75* . The diameter ratios for this canopy are D_o/D_c = 1.24*

* Performance Of And Design For Deployable Aerodynamic Decelerators, Technical Report No. ASD-TR-61-579, December 1953. p.66.

and $D_p/D_c = 0.76$* . The foregoing ratios represent nominal diameter to constructed diameter and projected diameter to constructed diameter respectively. Opening shock factor becomes a significant consideration if the parachute is ejected from a packed condition into a high velocity free-stream air flow. The opening shock factor (X) is determined from the expression:

$$X = F_o/F_s$$

where

F_o - opening shock force (lbs)

F_s - snatch shock force (lbs.

For the extended skirt canopy an opening shock factor of 1.8* is observed.

2.1.5.4 Parachute Sizing Calculations

2.1.5.4.1 Initial Conditions

Parachute canopy size determination is basically dependent upon the weight of payload to be recovered and the desired equilibrium velocity (V_e) at impact.

Total recovery system weight (W_t) is the sum of the payload weight (W_{pl}) plus the parachute weight (W_p).

Equilibrium impact velocity is largely determined by the design and weight of the instrumentation package to be recovered. If the instrumentation package is to be retrieved with little or no damage to its contents, it must be protected by well designed shock mounts or crushable shock absorption material on the exterior surface of the instrumentation capsule. On the other hand, landing shock can be further attenuated by sizing the parachute such that the impact equilibrium velocity will reduce the impact loading below the destructive g-limits of the instrumentation package or its components.

Assuming that an impact g-load limit has been determined for the instrumentation package or its most vulnerable component, an impact equilibrium velocity can then be determined to prevent g-loads beyond the destructive limitations of the retrieved instrumentation.

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* Performance Of And Design For Deployable Aerodynamic Decelerators, Technical Report No. ASD-TR-61-579, December 1953. p.66.

2.1.5.4.2 Example Sizing Calculations

In order that one may get a better understanding of the nominal parachute sizing procedure an example solution follows:

1. Assume that a 200 pound instrumentation package is to be recovered at an impact equilibrium velocity of 19.2 feet-per-second at sea-level. Solve for the parachute nominal values of canopy load ratio, drag area, parachute area, and diameter using a flat circular 10 percent extended skirt parachute canopy with an average steady state nominal drag coefficient $C_{D_o} = 0.725$.

2. The first step in the solution is to solve for the canopy load ratio expressed as

$$\frac{W_t}{C_{D_o} S_o} = \frac{\rho_o V_{e_o}^2}{2} = \frac{(0.002378 \frac{\text{lb-sec}^2}{\text{ft}^4})(19.2 \text{ fps})^2}{2} = 0.438 \frac{\text{lbs}}{\text{ft}^2} .$$

3. The second step solves for drag area expressed as

$$C_{D_o} S_o = \frac{2 W_t}{\rho_o V_{e_o}^2} = \frac{(2)(200 \text{ lbs})}{(0.002378 \frac{\text{lb-sec}^2}{\text{ft}^4})(19.2 \text{ fps})^2} = 456.3 \text{ ft}^2.$$

4. The third step solves for canopy area expressed as

$$S_o = \frac{2 W_t}{C_{D_o} \rho_o V_{e_o}^2} = \frac{(2)(200 \text{ lbs})}{(0.725)(0.002378 \frac{\text{lb-sec}^2}{\text{ft}^4})(19.2 \text{ fps})^2} = 630 \text{ ft}^2$$

5. The fourth step solves for canopy diameter expressed as

$$D_o = \frac{1.596}{V_{e_o}} \sqrt{\frac{W_t}{C_{D_o} \rho_o}} = \frac{1.596}{19.2 \text{ fps}} \sqrt{\frac{200 \text{ lbs}}{(0.725)(0.002378 \frac{\text{lb-sec}^2}{\text{ft}^4})}} = 28.31 \text{ ft}.$$

6. The fifth step solves for the construction diameter of the parachute, expressed as

$$D_c = \frac{D_o}{1.24} = \frac{28.31 \text{ ft}}{1.24} = 22.83 \text{ ft}.$$

The construction diameter (D_c) is the base dimension upon which the parachute manufacturer proportions canopy geometry in cutting gore patterns to the required size.

2.1.5.4.3 Generalized Sizing Calculations

The sizing relationships presented in 2.1.5.4.2 were expanded to provide a reasonable range of recovery applications with the objective of being able to determine canopy size required, based upon varying magnitudes of system total weight, final impact velocity, and canopy drag coefficient. All generalized sizing operations were based upon sea-level conditions. Tables of calculations show the variation of sizing parameters, using steps numbered 2 through 6 of 2.1.5.4.2. These tables reflect the variation of sea-level equilibrium velocity versus canopy load ratio, recovery system total weight versus canopy drag area at various values of canopy load ratio, canopy drag coefficient versus canopy area for values of canopy drag area required, and canopy nominal and construction diameters versus canopy nominal area.

2.1.5.4.4 Generalized Graphical Presentation for Determination of Parachute Size Required

Tables of calculations were prepared in graph form for convenience in determining the size of parachute canopy required. The graphs, numbered Figure 2.23 through Figure 2.26 correspond to these calculated tables. Figure 2.23 contains a shaded envelope indicating recommended impact equilibrium velocities and canopy load ratios for personnel and air cargo recovery *.

Example Using Graphs to Determine Parachute Size

The example cited in the graphs is denoted by dashed lines and the parameter to be solved for is denoted by the direction of the arrowheads on the

* Performance Of and Design for Deployable Aerodynamic Decelerators, Technical Report No. ASD-TR-61-579, December 1963, p.364.

dashed lines. Starting with Figure 2.23, assume that an instrumentation package designer decides that the package, which weighs 200 pounds cannot be impacted at a velocity any greater than 19.2 fps, due to g loadings involved. In Figure 2.23 locate the impact equilibrium velocity V_{e_o} = 19.2 fps along the ordinate. Reading over to the curve and down along the dashed line in the direction of the arrowheads

$$\frac{W_t}{C_{D_o} S_o} = 0.438 \text{ lbs/ft}^2 \text{ on the abscissa.}$$

Turning to Figure 2.24 on the ordinate at the 200 pound level read over to the curve

$$\frac{W_t}{C_{D_o} S_o} = 0.438 \text{ lbs/ft}^2 \text{ (interpolated)}$$

and down to a value of canopy nominal drag area of $C_{D_o} S_o$ = 457 ft^2. Now, assuming that the canopy type to be employed is a 10 percent extended skirt type with a nominal drag coefficient of C_{D_o} = 0.725, Figure 2.25 can be used to determine the nominal area of the canopy. Reading C_{D_o} = 0.725 over to the curve $C_{D_o} S_o$ = 457 ft^2 (interpolated) and down to the S_o scale, read a value of S_o = 630 ft^2. With the value S_o = 630 ft^2 located in Figure 2.26 along the abscissa read up to the intersection of the nominal and constructed diameter curves, respectively, D_o and D_c. Reading over to the ordinate in the direction of the arrowheads find D_o = 28.3 ft and $D_c = D_o/1.24$ = 22.8 ft. The determination of D_c is the final step in reading the sizing curves.

Through the foregoing generalized sizing graphs, it must be pointed out that only the instrumentation package weight was considered as the value W_t. This is not quite true because W_t is defined as the payload package weight plus the parachute weight or $W_t = W_{pl} + W_p$. It is therefore necessary to determine the weight of the previously sized parachute and resolve for the impact equilibrium velocity (V_{e_o}) with the additional weight of the parachute taken into consideration. Figure 2.27 is a plot of D_o versus W_p for various types of materials used in parachute construction. In the preceding paragraph D_o was found to be 28.3 ft. Reading along the ordinate in Figure 2.27 locate D_o = 28.3 ft. Following the dashed line in the direction of the arrowheads three material curves are intersected. The curve which delivers the heaviest weight of parachute for a nominal diameter $D_o = 28.3$ ft will be used. This weight W_p is approximately equal to 21 pounds. Therefore the total recovery system weight W_t would be equal to the payload package weight W_{pl} of 200 pounds plus the parachute weight W_p of 21 pounds or a total recovery system weight $W_t = 221$ pounds. This change in weight would increase the canopy load ratio thereby causing an increase in touch-down velocity. The increase in velocity at touch-down is found by the following expression:

$$V_{e_o} = \sqrt{\frac{W_t}{C_{D_o} S_o} \cdot \frac{2}{\rho_o}} = \sqrt{\frac{221 \text{ lbs}}{(0.725)(630 \text{ ft}^2)} \cdot \frac{2}{(0.002378 \frac{\text{lb-sec}^2}{\text{ft}^4})}} = 20.17 \text{ fps}$$

The additional weight of the parachute when combined with the payload package weight has increased V_{e_o} from 19.2 fps to 20.17 fps or a net increase of 0.97 fps which is negligible.

2.1.5.5 Geometry of the Flat Circular 10 Percent Extended Skirt Parachute

The inflated shape of the flat circular 10 percent extended skirt parachute is largely determined by gore geometry. The reference "flat circular" implies a canopy of n number of gores, when assembled, would lay flat on a planar surface. The reference "10 percent extended skirt", refers to an extension of the gores at their base, a distance of 10 percent D_c or 10 percent of the constructed diameter which was calculated in the step numbered 6 of 2.1.5.4.2. Figure 2.28 illustrates the recommended gore geometry of the flat circular 10 percent extended skirt parachute. It is to be noted that all dimensions are based upon the constructed diameter D_c. Suspension line length is denoted as L_s and the value n denotes the number of gores comprising the entire canopy. The gore area is that which is enclosed by the heavy lines in Figure 2.28. The area below the skirt line composes the extended skirt portion of the gore.

2.1.5.6 Parachute Cost Evaluation

Cost information with regard to type of parachute referred to in this report appears in Figure 2.29. This information is presented in the form of a curve of parachute cost versus parachute constructed diameter. The cost information is based upon 1967 manufacturer's cost quotations to the customer.

2.2 Test Site Survey

There is an obvious necessity to ensure maximum safety in conducting a program involving high yield explosive gas mixtures. The problem of safety is further complicated by the use of a free floating balloon. The most desirable location for conducting such tests would have to provide a high probability of cloudless, low ground wind days, no population or structures and comply with the FAA regulations* encountered in the continental United States.

2.2.1 Geographical Considerations

These factors would indicate that the ideal location for performing high altitude SLEDGE field tests would be over water using a naval vessel as a launch, tracking, and recovering vehicle. The launch vehicle would undoubtedly be an LST or equivalent. Although expensive to operate, it offers many advantages. During launch, the LST can be headed in a direction to neutralize the wind effects. An LST can be equipped with tracking and communications to monitor and control the flight phase of the program and can base launch recovery vehicles. The major disadvantage of using an LST would be the cost of operation and difficulty of acquiring this type of facility for this purpose.

A remote Pacific island could be a potential test site offering about the same advantages as an LST. Wind effects during launch cannot be compensated for. But winds are generally of a predictable velocity and compensation from ground wind effects can be provided. The operational costs would again be higher when one considers transportation of personnel and equipment to the test site.

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* Moored Balloons, Kites, Unmanned Rockets, and Unmanned Free Balloons; Title 14 Chapter 1, Subchapter F, Part 101.

Operation in the continental United States would almost certainly require the tests to be performed at a fully instrumented range where an effective range safety system has been established. Also the test site should be relatively large to accommodate the balloon flight. Several bases exist which meet these requirements. Eglin AFB, Florida, Edwards AFB, California, Nevada Test Site, Nevada, and White Sands Missile Range, New Mexico. These bases, with the exception of White Sands, are oriented toward different missions and are not likely to be available to support the high altitude SLEDGE program.

2.2.2 Meteorological Support

An important factor in balloon launch is the forecast of weather, particularly winds, both on a 24 hour basis and immediately proceeding a launch. The type of meteorological data (vertical information on transient air cell over prospective launch site) required are: Temperature vs. altitude; barometric pressure vs. altitude; wind direction and velocity vs. altitude; precipitation (rain, hail, etc.); cloud ceilings and percent obscurity of clouded sky; turbulence, icing levels; and visibility.

The above items are the basic weather phenomena having a direct effect on the balloon launch and flight operations.

Due to the rather delicate nature of balloon launch conditions required, the ideal operation would be conducted under absence of any winds from the surface to detonation altitude accompanied by unlimited visibility. This ideal meteorological condition rarely exists, therefore the minimum winds and maximum visibility conditions available must be accepted.

In order to plan and initiate launch operations it becomes necessary to have access to meteorological forecast data. Every six hours the United States Weather Bureau's Aviation Forecast Centers prepare detailed flying weather forecasts for 12-hour periods for about 385 air terminals in the United States including Alaska and Hawaii. In addition, 24-hour terminal forecasts are provided for about 120 major airports throughout the country. Every six hours a detailed 12-hour area forecast is prepared for each of the 29 areas into which the continental United States has been divided for forecasting purposes.

All United States Weather Bureau Flight Service Stations having voice facilities on continuously operated radio ranges or radio beacons broadcast weather reports at 15 and 45 minutes past each hour. The 45-minute past the hour broadcast is an "airway" broadcast consisting of weather reports from important terminals located on airways within approximately 400 miles of the broadcasting station. The 15-minute past the hour broadcast is an"area" broadcast consisting of weather reports from the stations within approximately 150 miles of the broadcasting station.

At each station, the "airway" broadcast is as follows: Alert notice announcement; SIGMET (Significant Meteorology) or advisory for light aircraft (if available); PIREPS (Pilot reports) when available; Radar reports (if available); aviation weather; flight information - any nonmeteorological information not a part of a weather report but which requires broadcast; additional special weather reports and some NOTAM'S (Notices to airmen) are broadcast off-schedule upon receipt; winds aloft forecasts are transmitted only on request.

The U.S. Weather Bureau operates a 97-station network of weather radars which are operated continuously if any precipitation capable of being detected is present or expected. These stations are generally spaced in such a manner as to enable them to detect and identify the type (snow, rain) of most of the precipitation east of the continental divide.

If any weather is detected, a scheduled radar observation is taken at 45 minutes past each hour; more often if the characteristics (speed, intensity, etc.) are changing rapidly. These observations are transmitted to U.S. Weather Bureau and FAA Stations and are available for use in pre-flight and in-flight planning. In addition, an hourly radar summary and a three-hourly radar summary facsimile chart; are prepared by the Radar Analyses and Development Unit in Kansas City, Missouri. The hourly radar summary is transmitted on Service A teletypwriter to all U.S. Weather Bureau and Flight Service Stations, and the radar chart is available to all subscribers to the facsimile network. A map of the continental radar reporting network is shown in Figure 2.30.

2.2.3 Weather Input to Balloon Launch Operations

If a land based operation is selected, the nearest USWS Flight Service Station will provide metro prognostications and upper air soundings. Sea operations can acquire metro data from radio broadcasts to water borne commerce. In addition, an aerological measuring set such as the AN/PMQ-5 from the Bureau of Aerology, U.S. Navy, should be obtained for emplacement on-board ship or at the launching site. Figure 2.31 shows the possible methods of metro data relay to the launch sites. The AN/PMQ-5 is a manually operated portable meteorological station weighin 14-1/2 pounds. It measures atmospheric pressure, temperature, relative humidity, wind direction, and velocity. This unit is manufactured by the Bendix Frieze Company and is similar to the AN/PMQ-4 manufactured by Kollsman.

The Radiosonde is the most widely used instrument for obtaining upper air data. These balloon-borne equipments carry pressure, temperature, and humidity measuring devices and a radio transmitter for telemetering the information back to ground. (See Section 2.1.4)

In the event that operations are conducted at a missile range, a complete local meteorological facility is available to provide on-range weather predictions.

2.2.4 Tracking Equipment

The importance of tracking facilities has been discussed in Section 2.1.4. Several information sources were reviewed to determine instrumentation and tracking facilities at potential launch sites. The following table summarizes the results of the review:

Location	Range Instrumentation	Comments	Reference
White Sands Missile Range, New Mexico	AN/FPS-16 Radar; AN/GMD-1 rawin set; AN/AMT-4B radiosonde; AN/AMT-15 radiosonde	balloon borne radar reflector 6" diameter; ambient temperature - 53°C	(1), (13) *
Eglin AFB, Florida	"satellite tracking facility"	also Santa Rosa Island data facility	(2)
	AN/FPS-16 radar		(7)

* List of References at end of this report.

Location	Range Instrumentation	Comments	Reference
Wallops Island Station, Virginia (NASA)	AN/FPS-16 radar; radar is equipped with digital readout. SCR-584 radar; SCR-584-Mod II radar		(3)
Weather Bureau Station, Cape Hatteras, North Carolina	SP-1M radar		(3)
Kwajalein Atoll, Marshall Islands	TRADEX tracking radar; IBM 7090 computer		(4)
NASA Mobile Launch Platform, NSTS Croatan			(4)
Holloman AFB, New Mexico	AN/FPS-16 radar; cinetheodolites; radiosondes		(5)
Cape Kennedy, Fla.	AN/FPS-16 radar; AN/GMD-1B rawinsonde		(6),(8)
Point Arguello, Calif. (Western Test Range)	Rawinsondes	adjoins Vandenberg Air Force Base	(9)
AEC Nevada Test Site	"FAA and USAF radars"		(10)
Chico, Calif. (AFCRL)			(12)
Palestine, Texas (NCAR)	"90-channel digital command telemetry system"	NCAR Balloon Test Facility	(11)
Pt. Mugu, Calif. (Pacific Missile Range)	AN/FPS-16 radar		(14)
Fort Churchill, Manitoba, Canada	DOVAP tracking; ballistic cameras		(15)

It is evident that the most common tracking radar is the AN/FPS-16. This high precision tracking system is available at most instrumented test ranges. Also the AN/GMD series of radiosonde/direction-finding systems also seems quite common.

2.2.5 Recommended Test Site

A cursory study of possible test sites was conducted as part of this program. It is recommended that the White Sands Missile Range, New Mexico, be utilized for the initial development phases of the High Altitude Blast Generation System. This site was selected for initial tests because of location, facility support, and ability to meet the safety requirements for High Altitude Blast Generation System tests. Although other test sites mentioned previously would satisfy the requirements of a High Altitude SLEDGE System, they were disregarded because the scope of their mission would not include tests of this type. The Air Force Cambridge Research Laboratory has performed a similar survey as part of the BANSHEE program and concurs with this recommendation.

As the High Altitude Blast Generation System becomes operational, it may be necessary to consider more remote locations, than the White Sands Missile Range. Whatever the program objective may be at that time it is recommended that a remote Pacific island be considered as a transition from the development stage to a fully operational system. Kwajalein atoll, in the Marshall Islands, appears to be the best suited location.

The fully operational requirements of a High Altitude SLEDGE system dictates complete mobility. For the fully operational system it is recommended that field tests be conducted over-water using an LST.

The field test costs would be lowest for White Sands Missile Range and progressively higher for Kwajalein and over-water operations. These qualitative cost estimates were obtained without regarding the availability of recommended test sites. Quantitative cost estimates and test site availability would have to be determined at the time specific information concerning test scheduling was available. However, for budgetary purposes it has been suggested by AFCRL a preliminary cost of $30,000 per event be considered for initial tests at White Sands Missile Range.

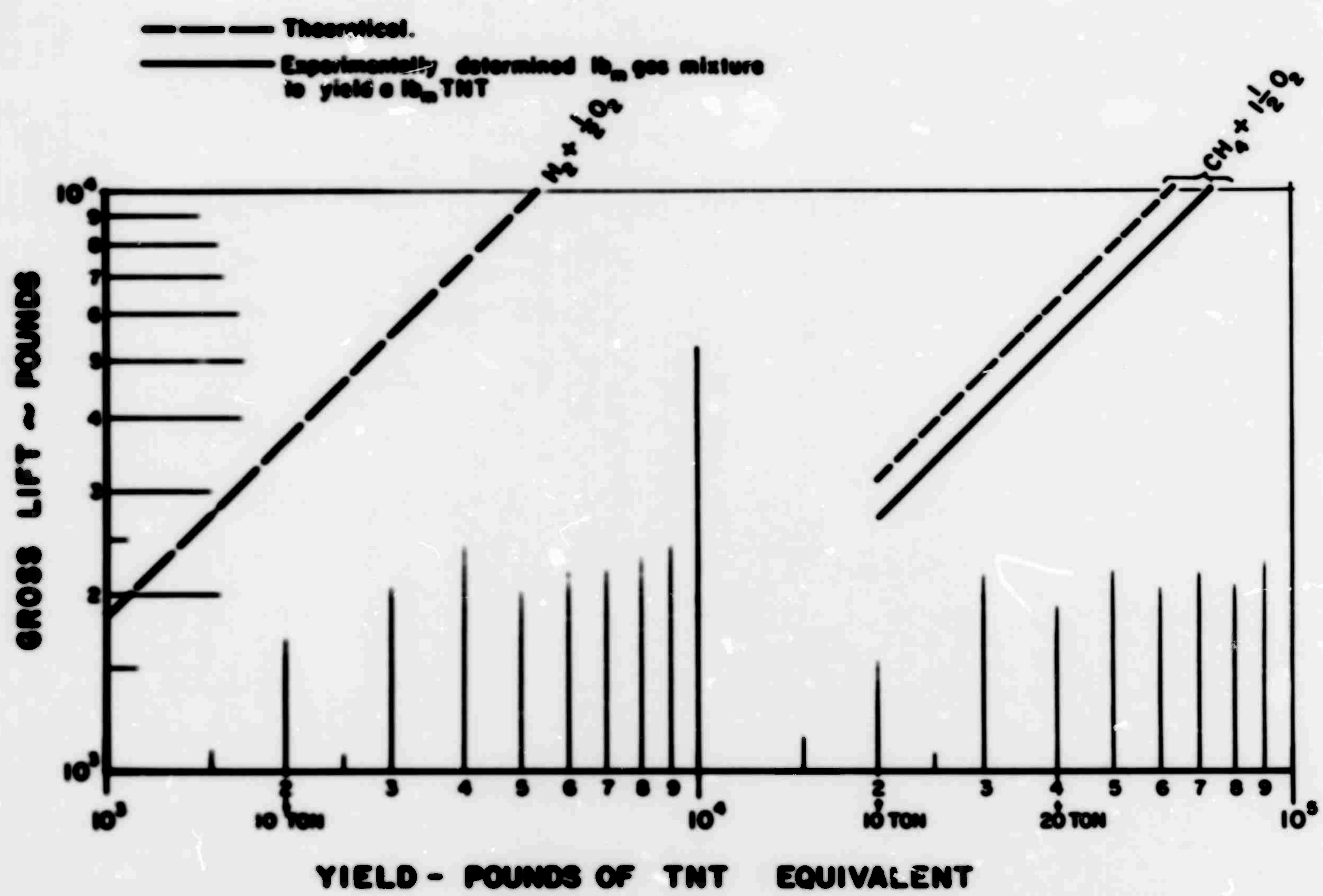


Figure 2.1, GROSS LIFT VS YIELD

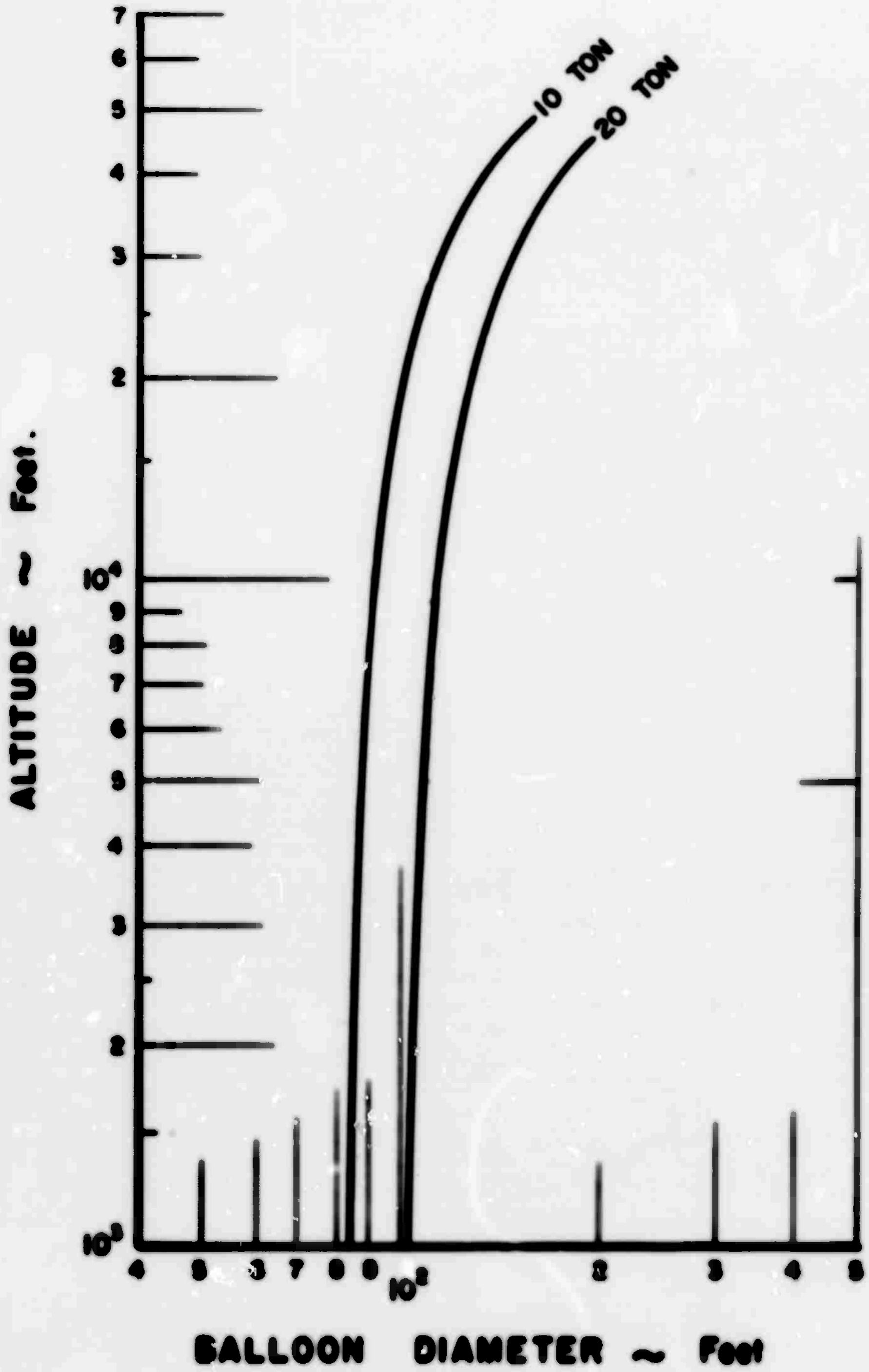


Figure 2.2, ALTITUDE VS BALLOON DIAMETER FOR VARIOUS TNT YIELD EQUIVALENTS - LB. TO LB. BASIS, O_2 TO CH_4 = 1.5.

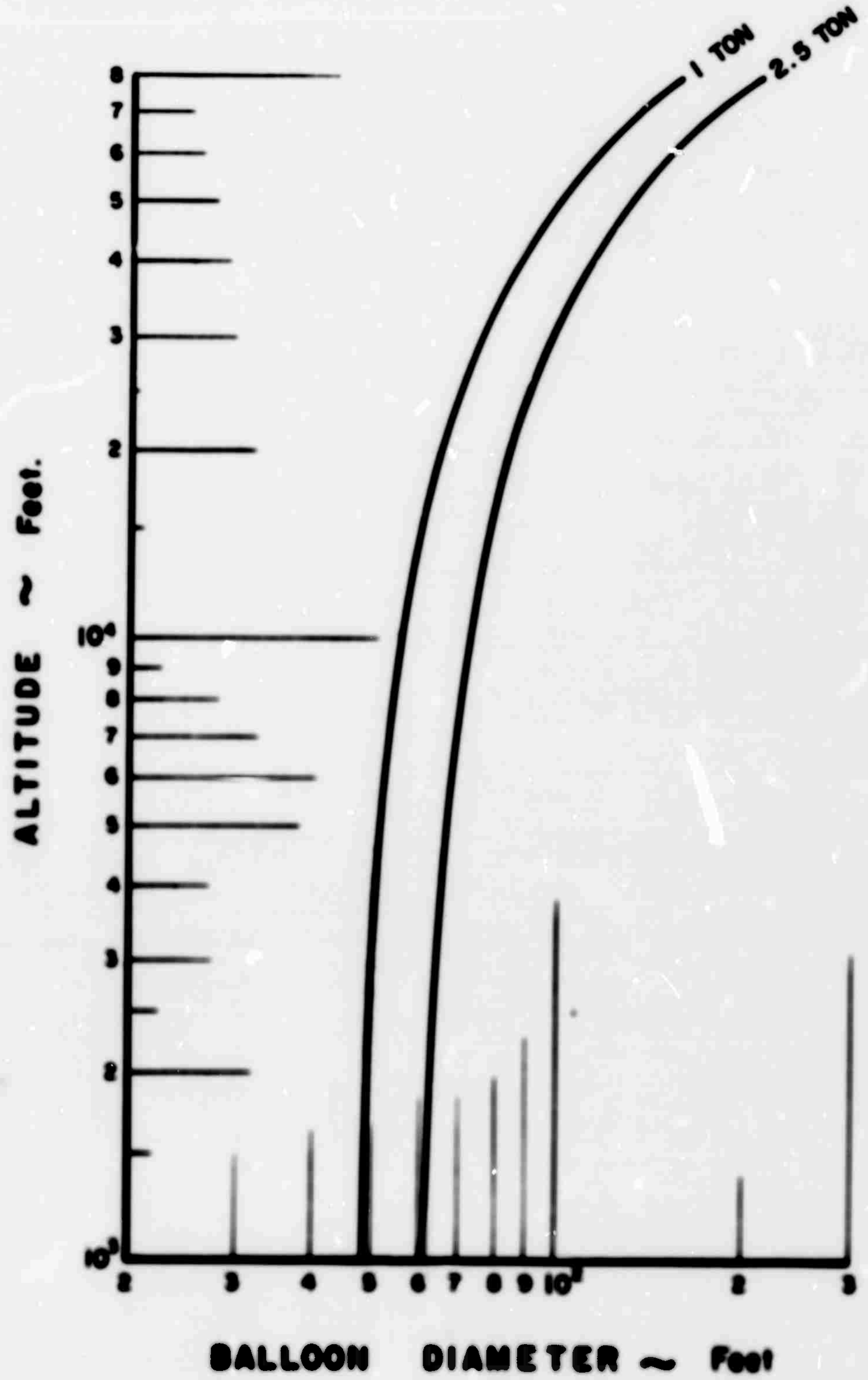


Figure 2.3. ALTITUDE VS BALLOON DIAMETER FOR VARIOUS TNT YIELD EQUIVALENTS - LB. TO LB. BASIS, O_2 TO H_2 = 0.5.

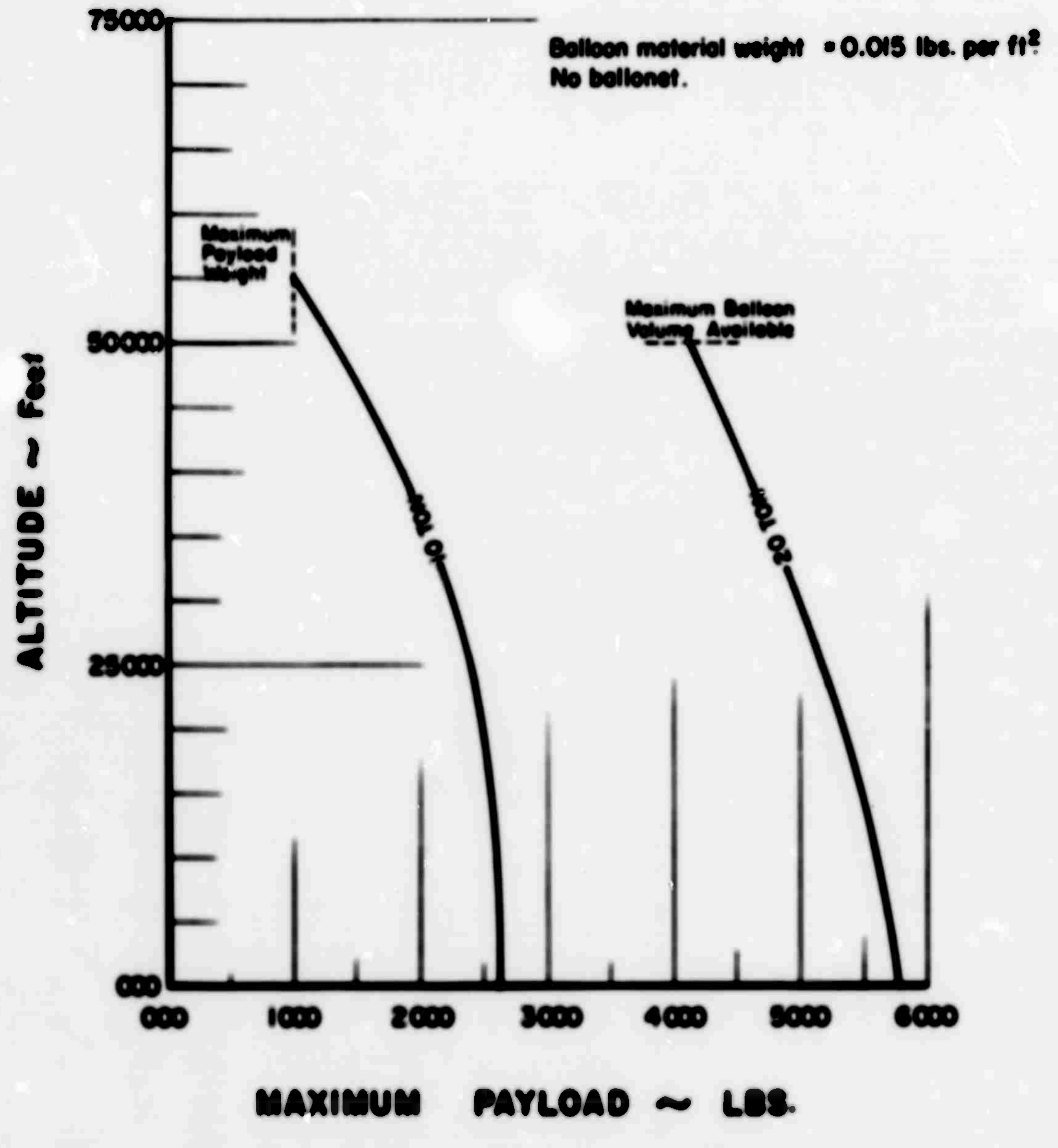


Figure 2.4, ALTITUDE VS MAXIMUM PAYLOAD WEIGHT FOR VARIOUS YIELDS, OXYGEN TO METHANE = 1.5

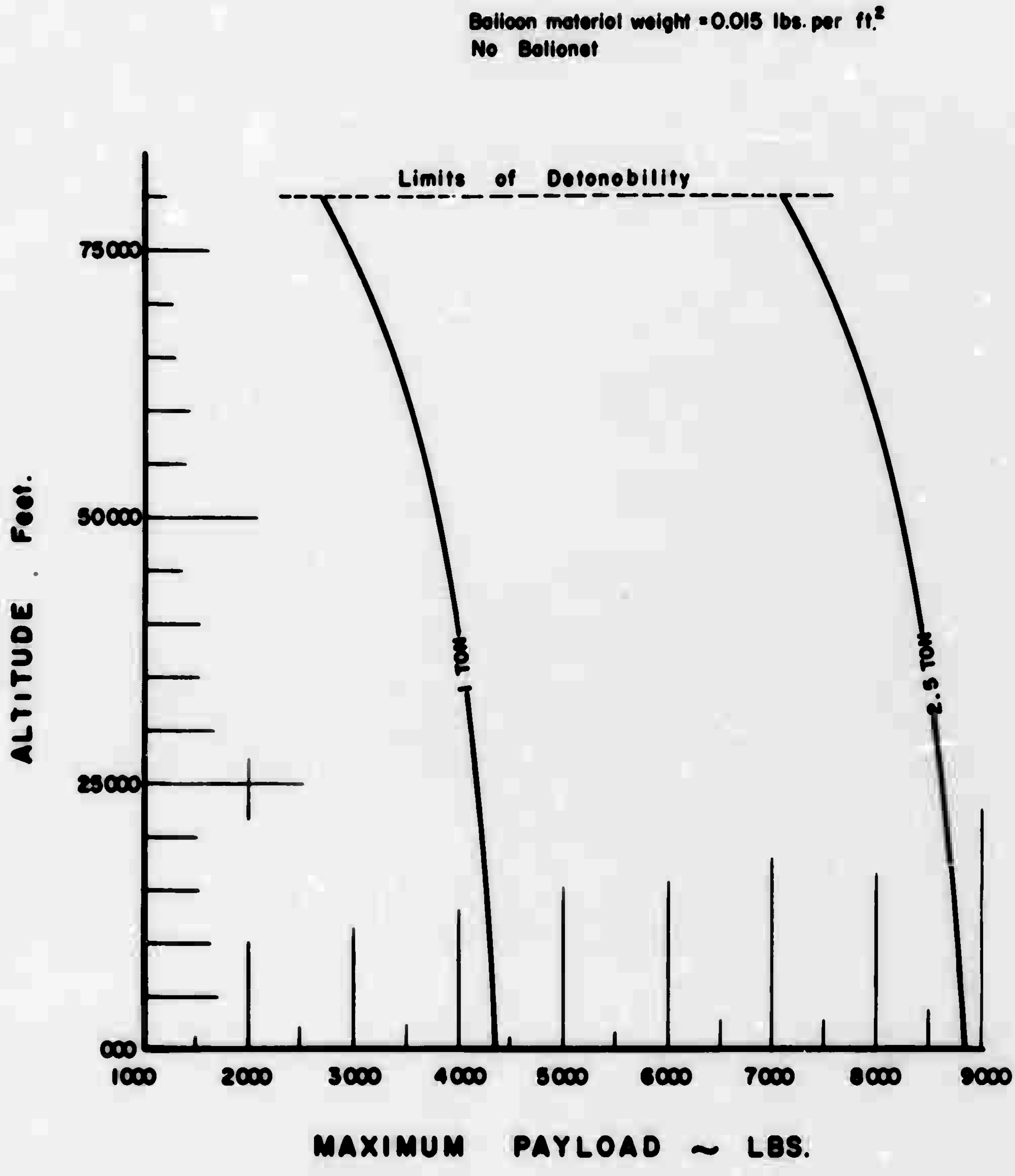


Figure 2.5 ALTITUDE VS MAXIMUM PAYLOAD WEIGHT FOR VARIOUS YIELDS, OXYGEN TO HYDROGEN = 0.5

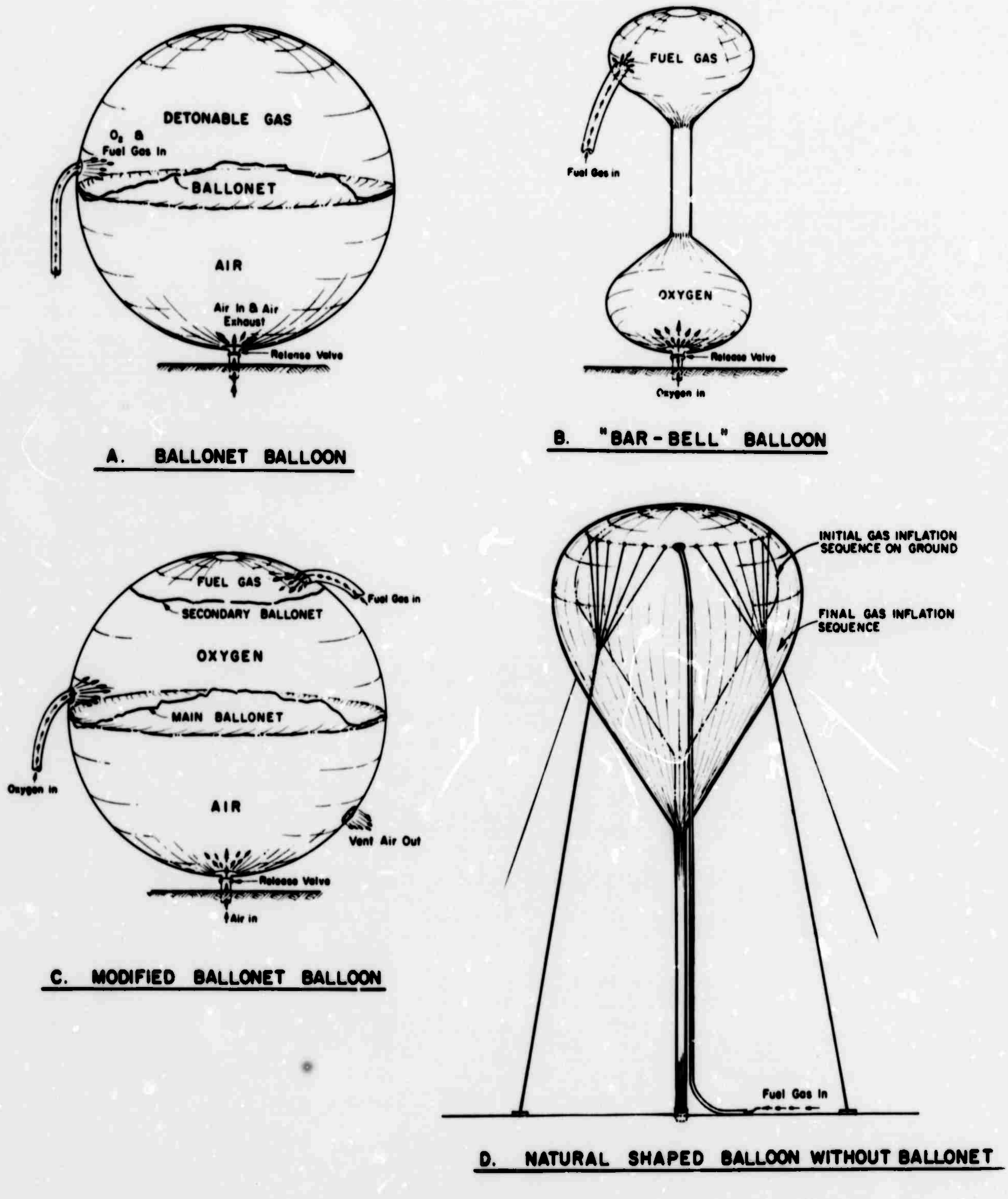


Figure 2.6 BALLOON CONCEPT FOR HIGH ALTITUDE SLEDGE

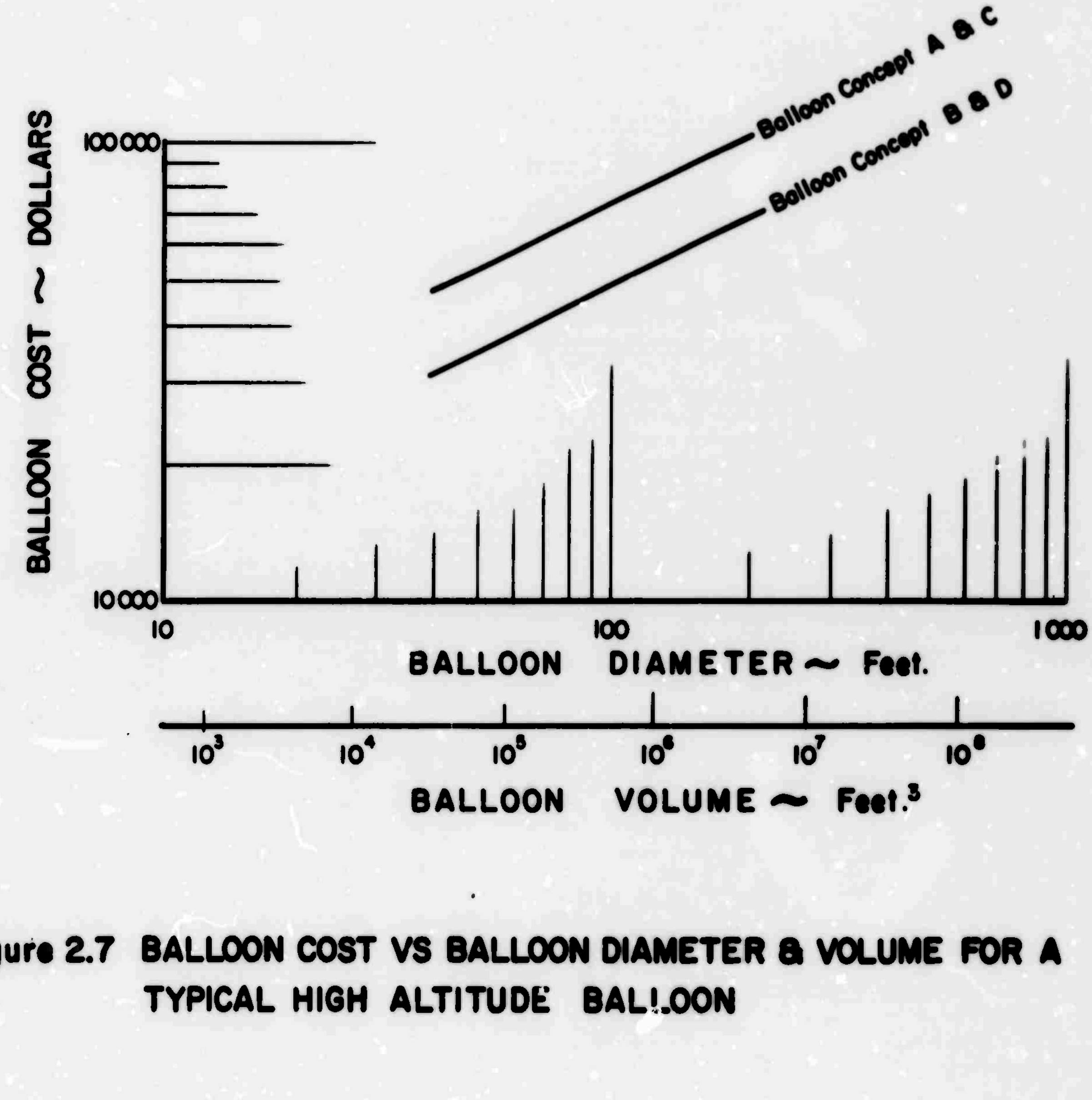


Figure 2.7 BALLOON COST VS BALLOON DIAMETER & VOLUME FOR A TYPICAL HIGH ALTITUDE BALLOON

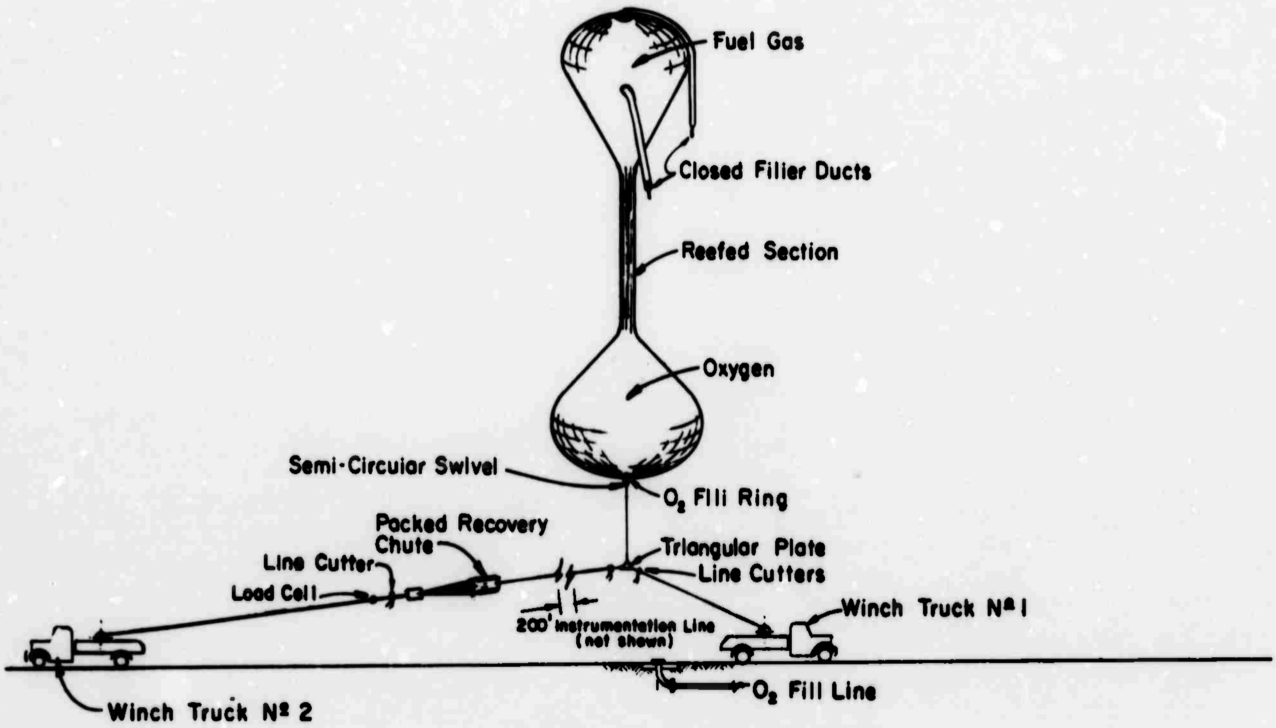


Figure 2.8 REMOTE WINCHING OPERATION

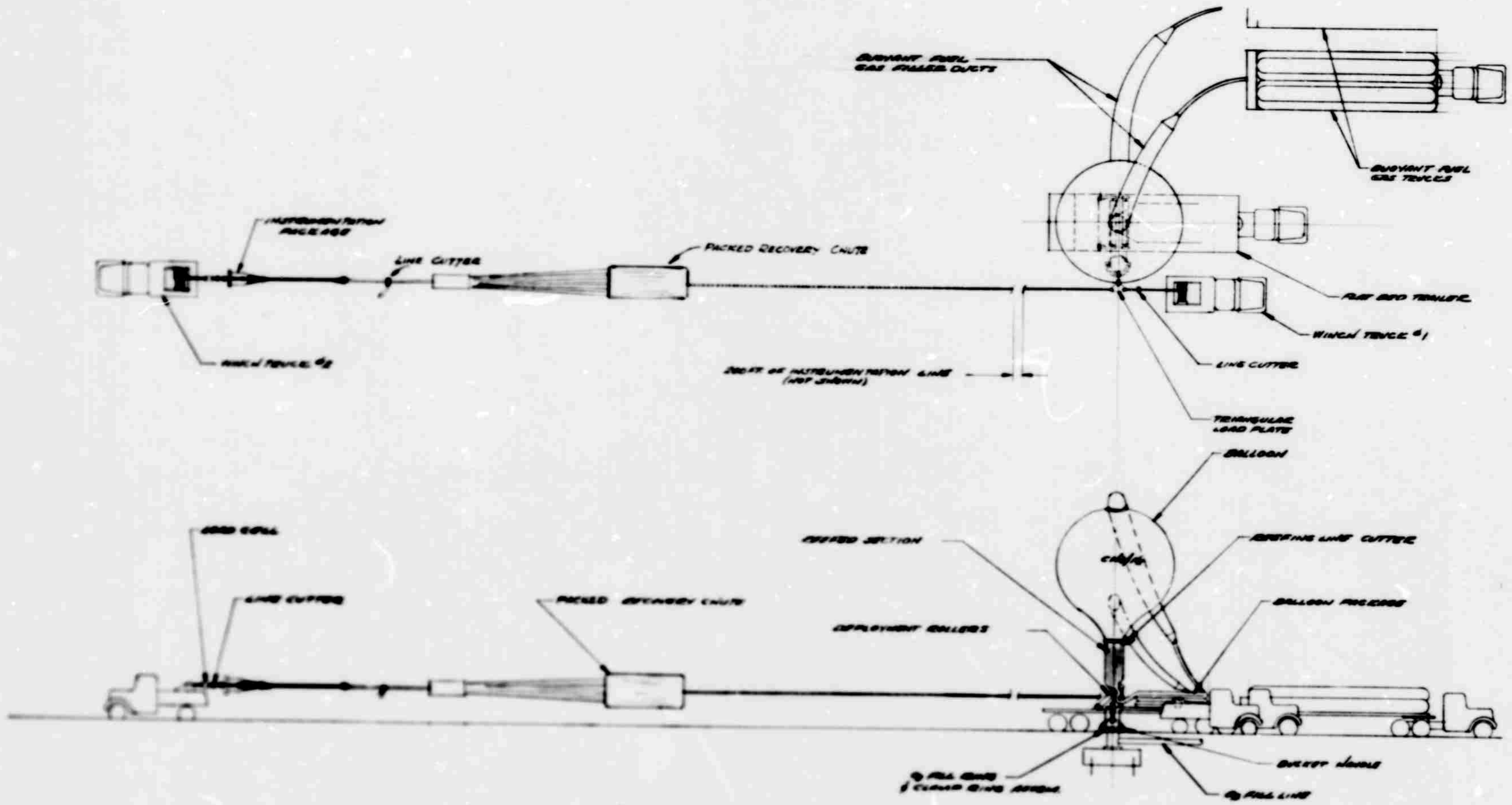


Figure 2.9 PRIMARY LAUNCH TECHNIQUE

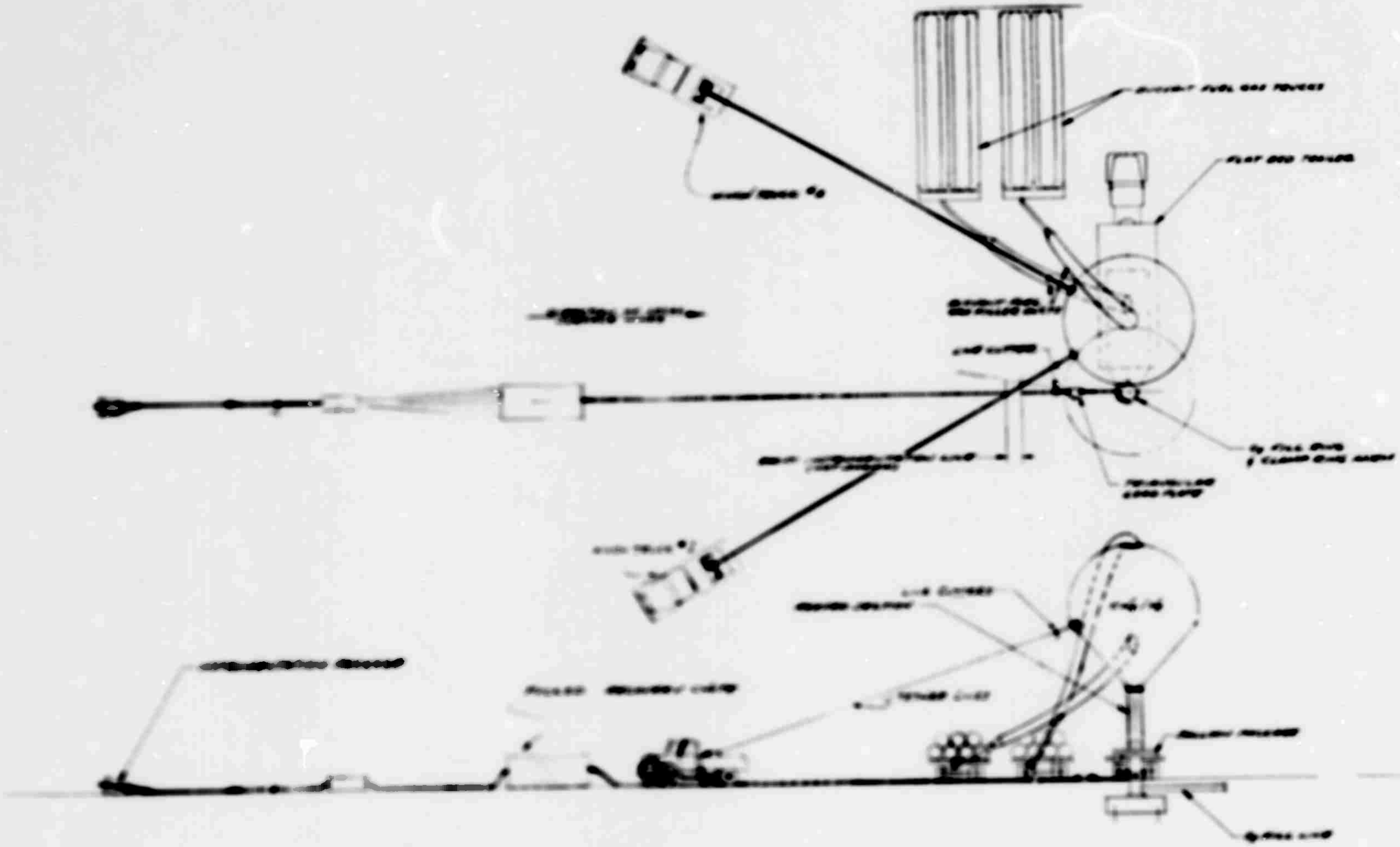


Figure 2.10 ALTERNATE LAUNCH TECHNIQUE - 1

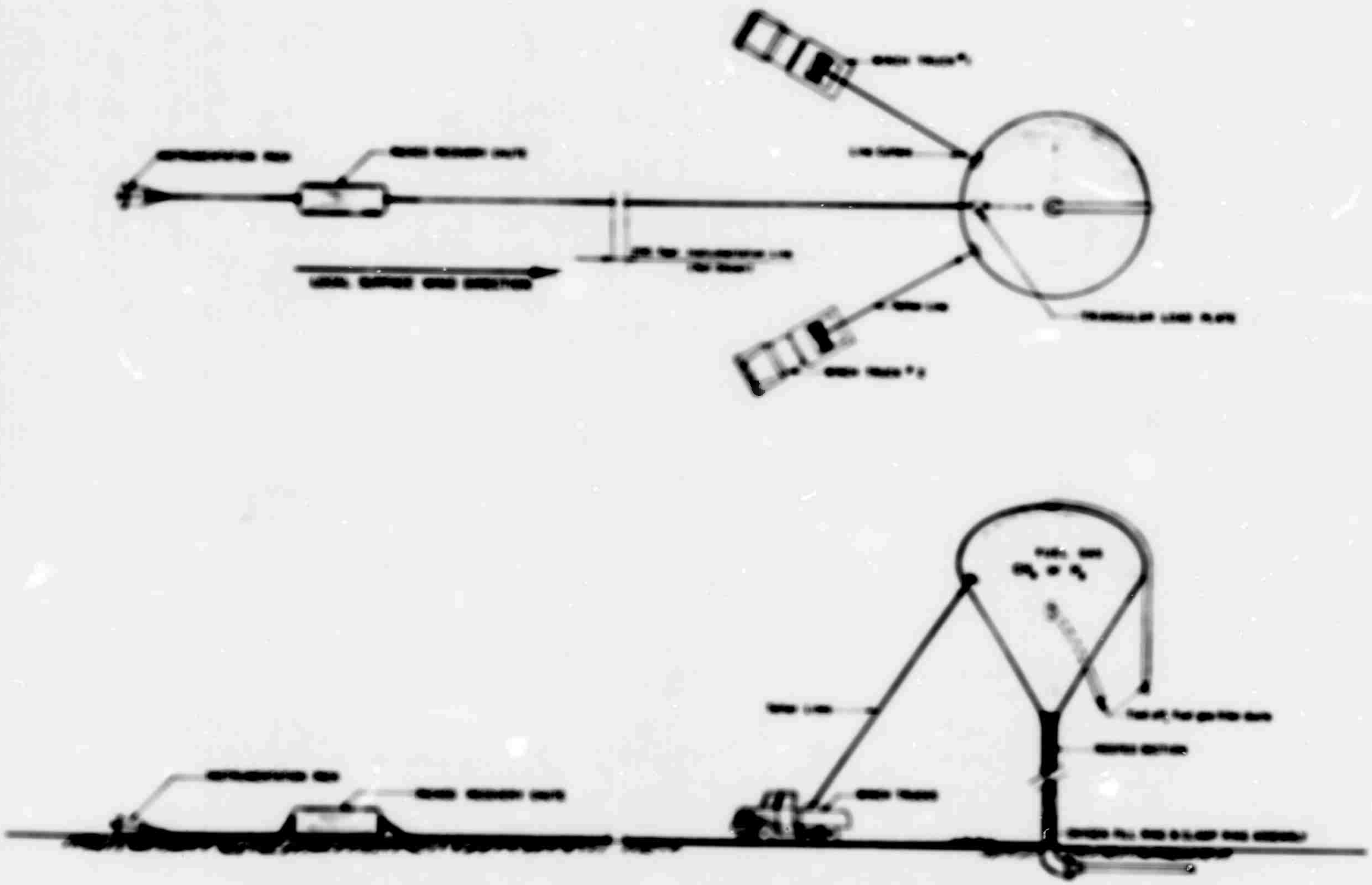


Figure 2.10A ALTERNATE LAUNCH TECHNIQUE - II

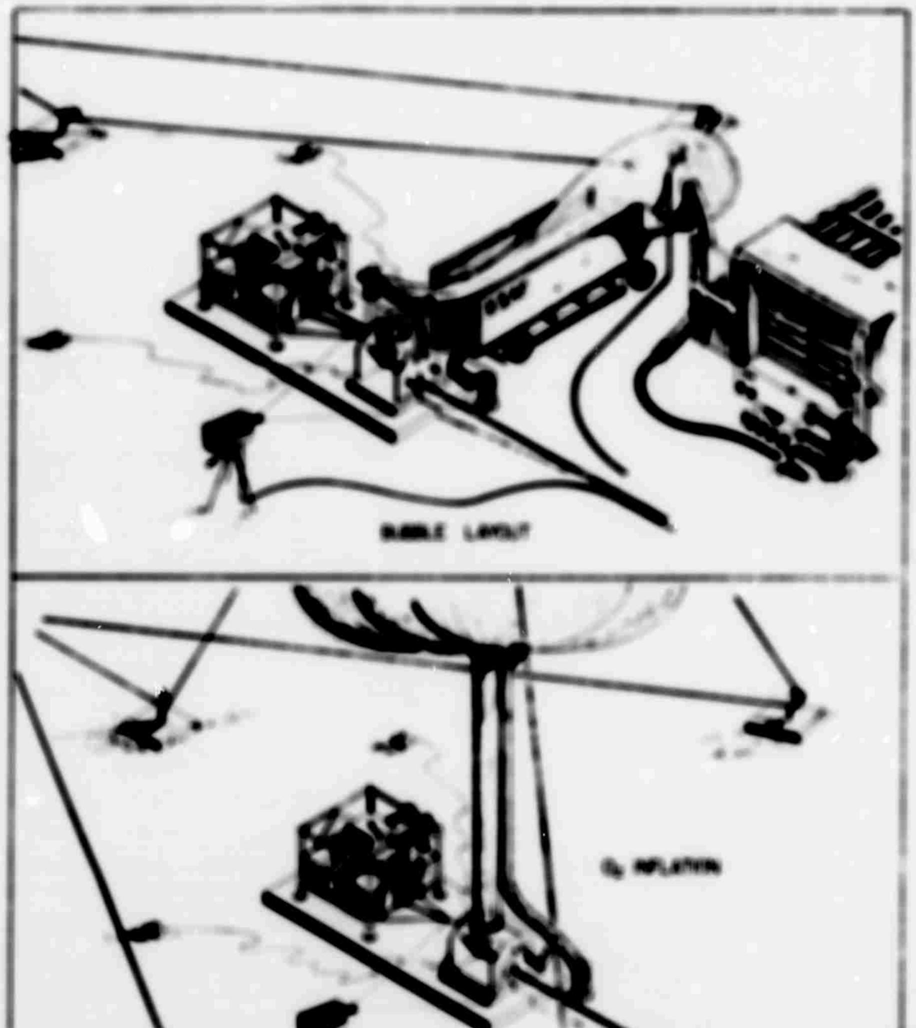


Figure 2.11 AFCRL LAUNCH TECHNIQUE

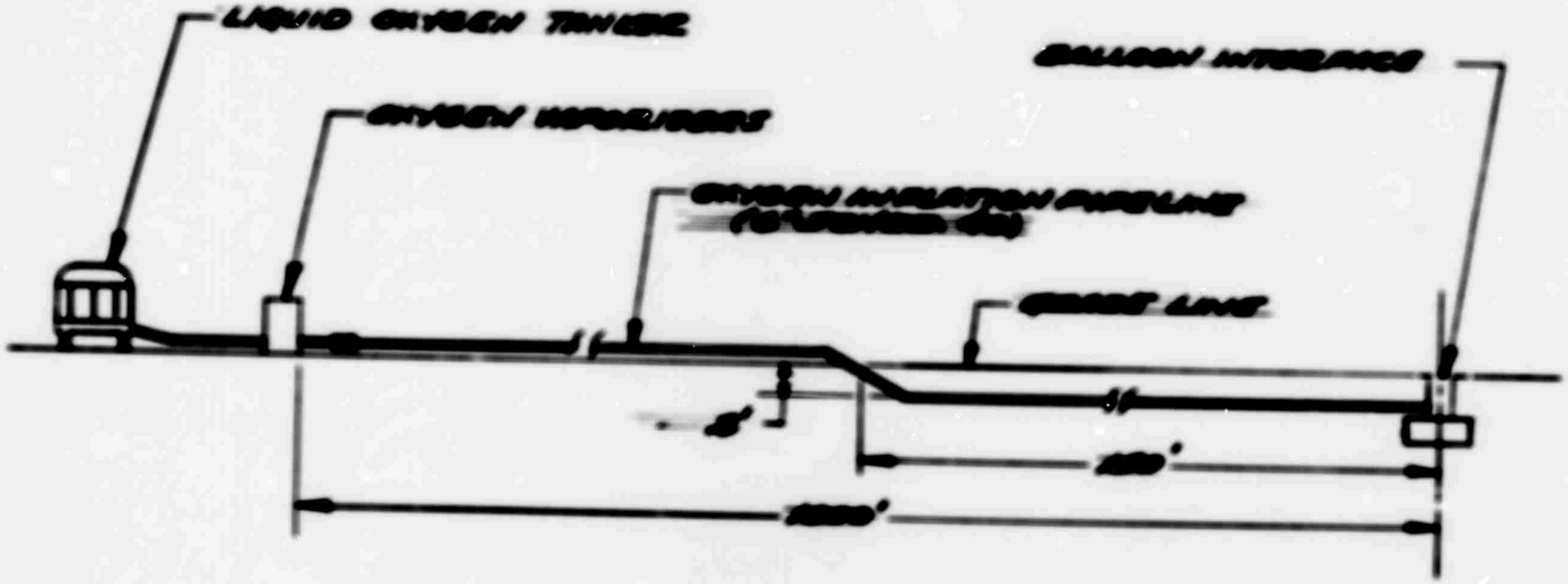


Figure 2.12 OXYGEN LOADING SYSTEM

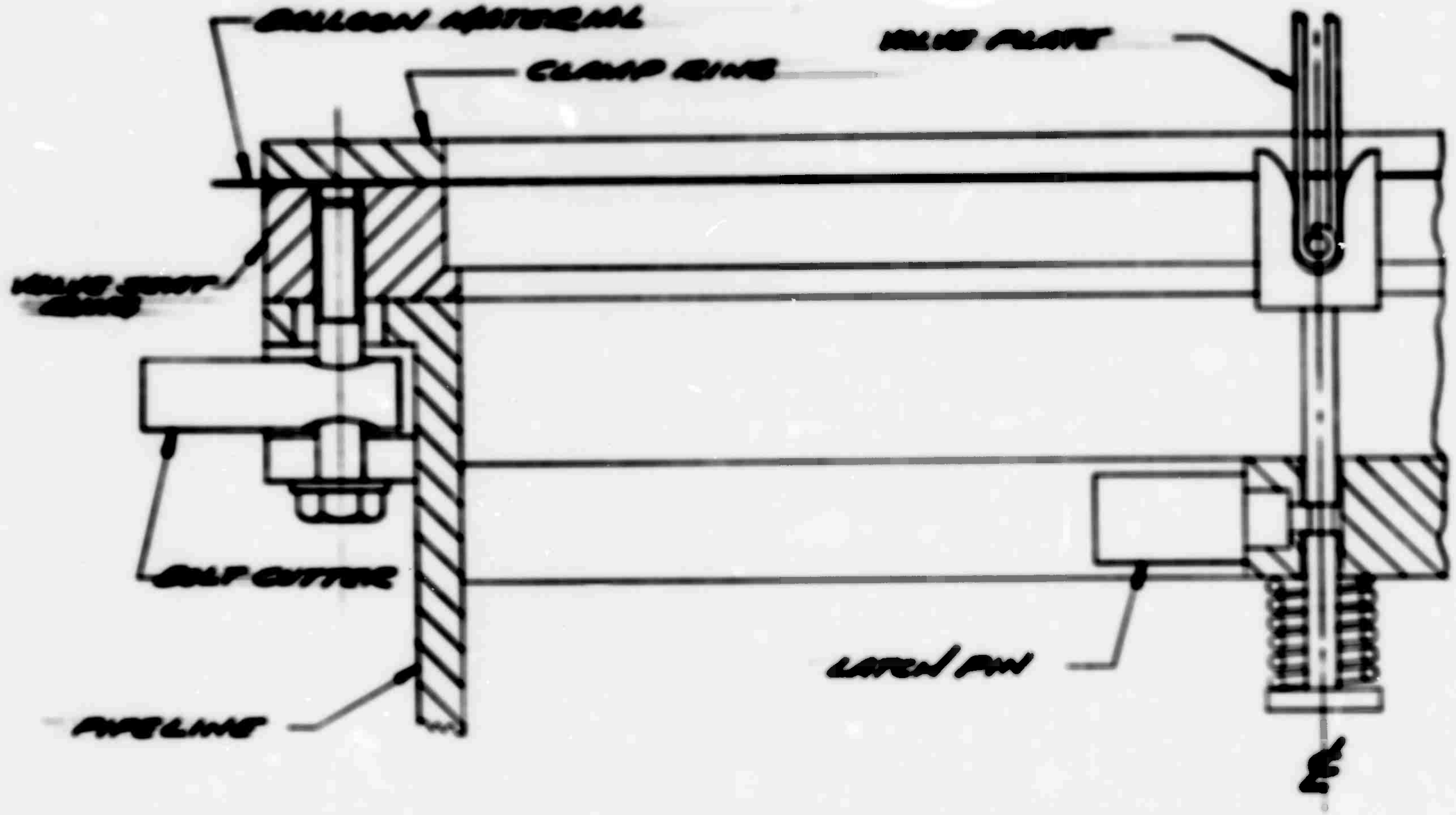
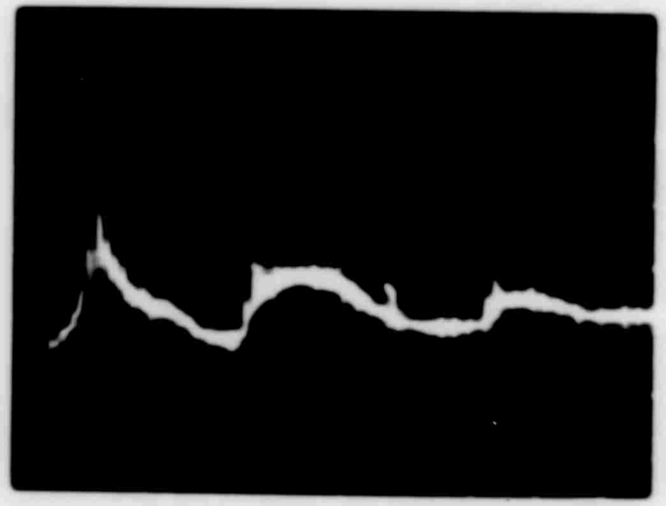


Figure 9.13 PROPOSED OXYGEN INFLATION VALVE

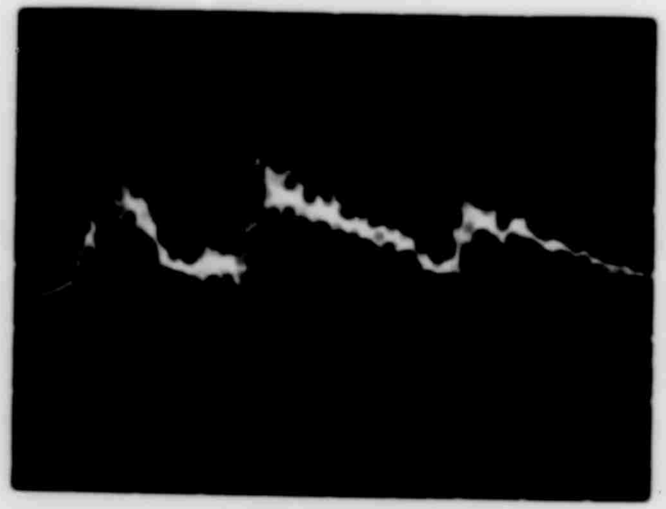
10 psi/cm
2 ms/cm



10 psi/cm
5 ms/cm

<u>Schaevitz Bytrex</u>

10 psi/cm
2 ms/cm



10 psi/cm
5 ms/cm

<u>Kistler Piezotron</u>

Figure 2.14 TRANSDUCER SHOCK TUBE TESTS

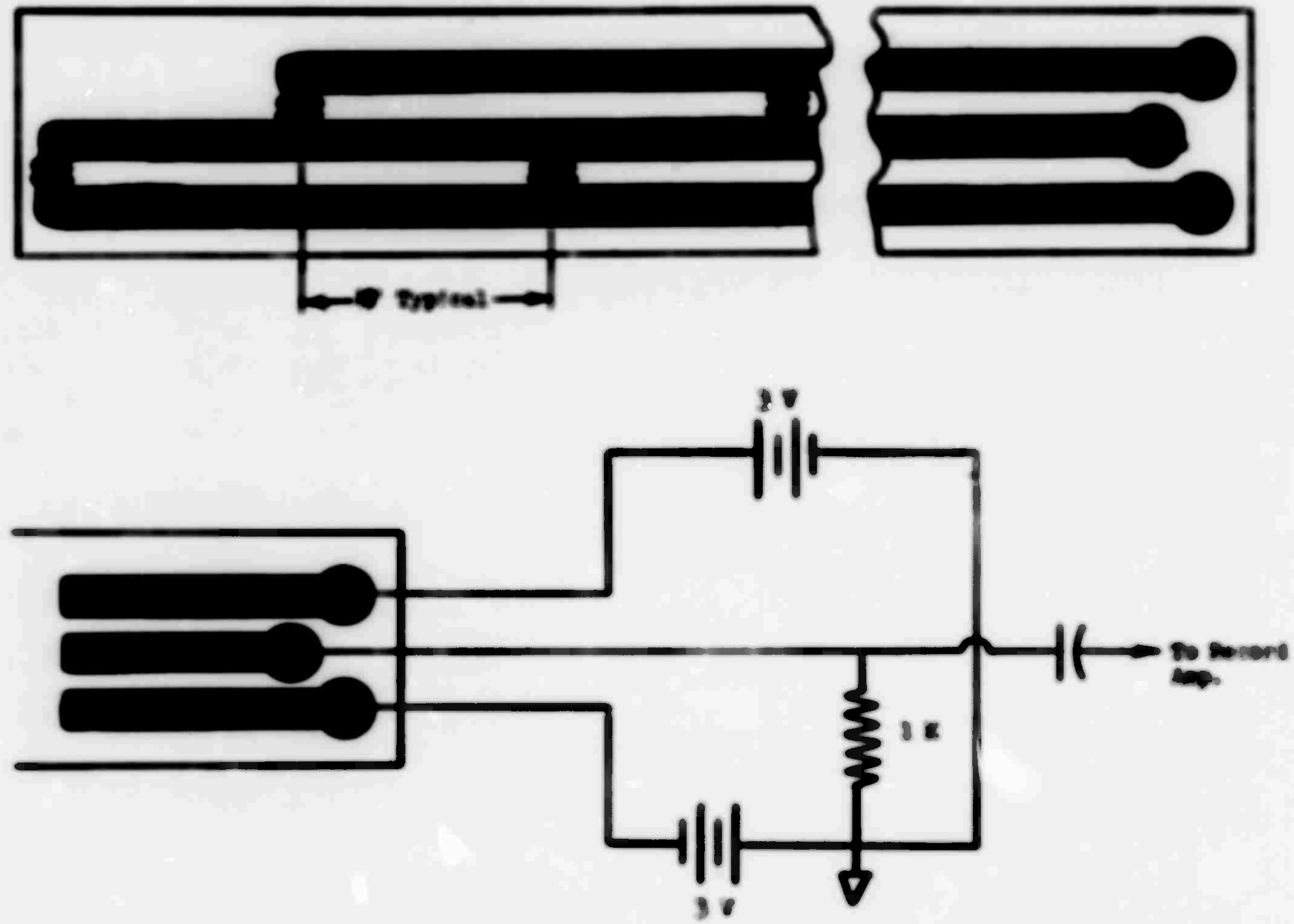


Figure 2.15 Typical Sensor Strip
(Electronic Time Gage)

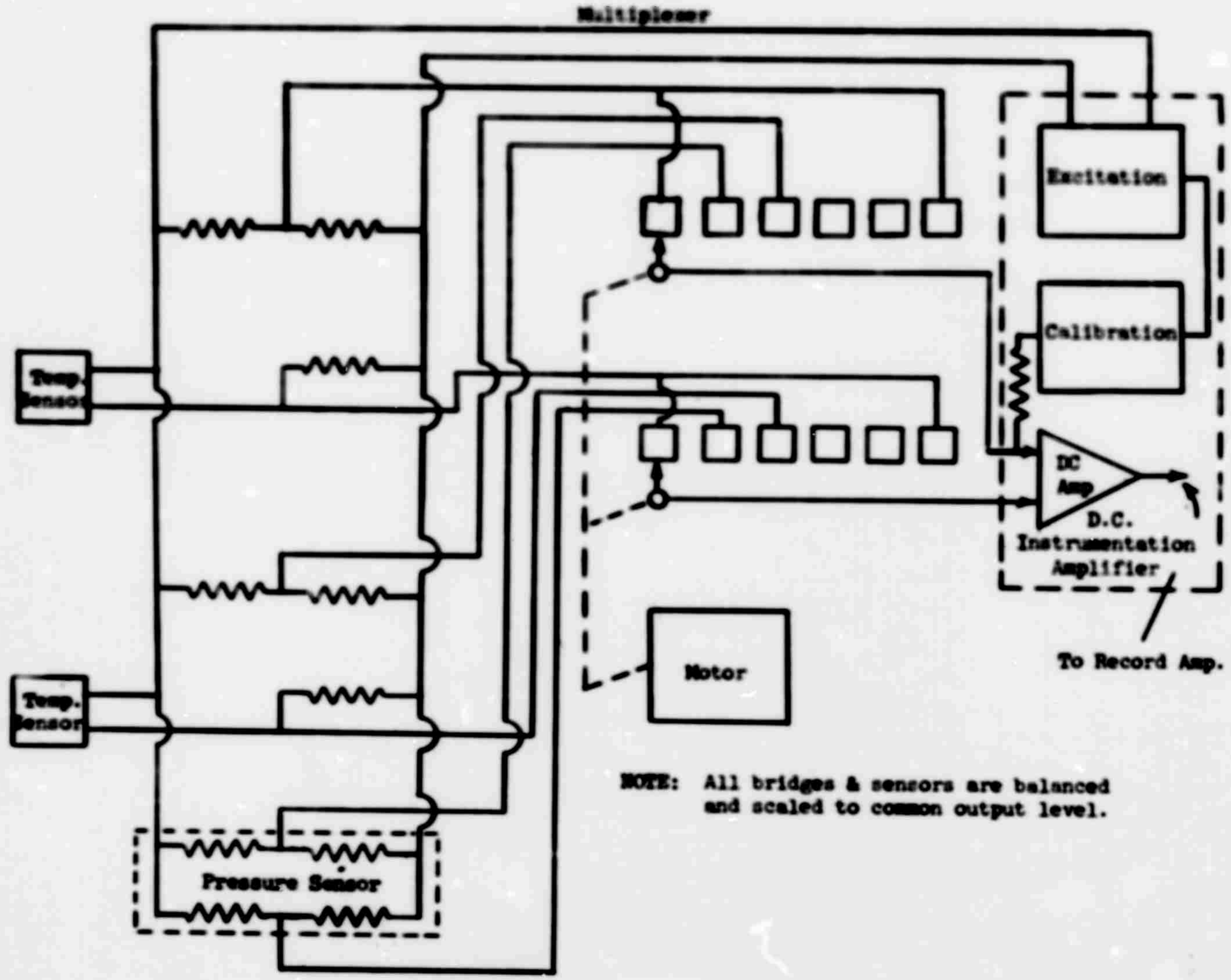
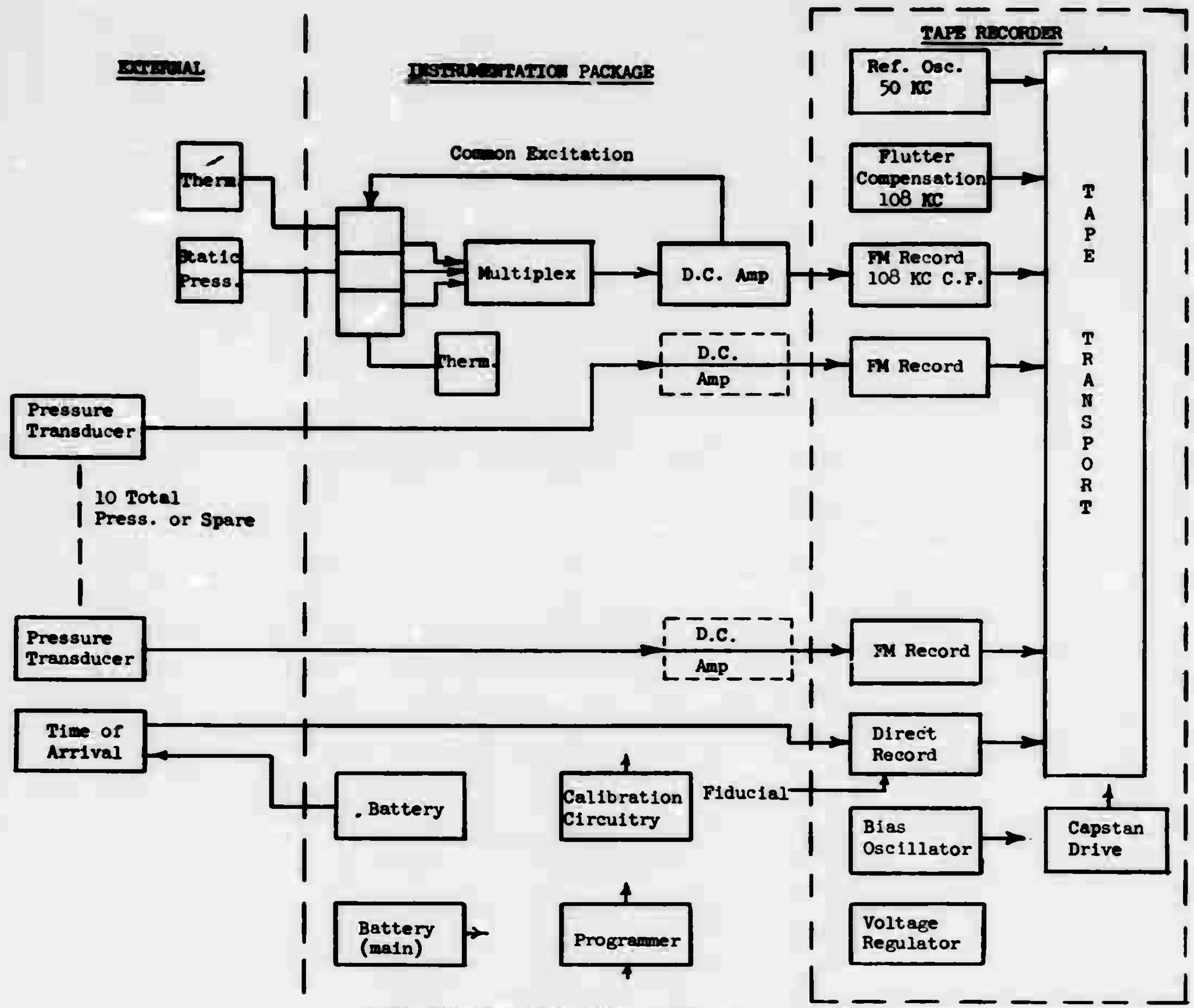
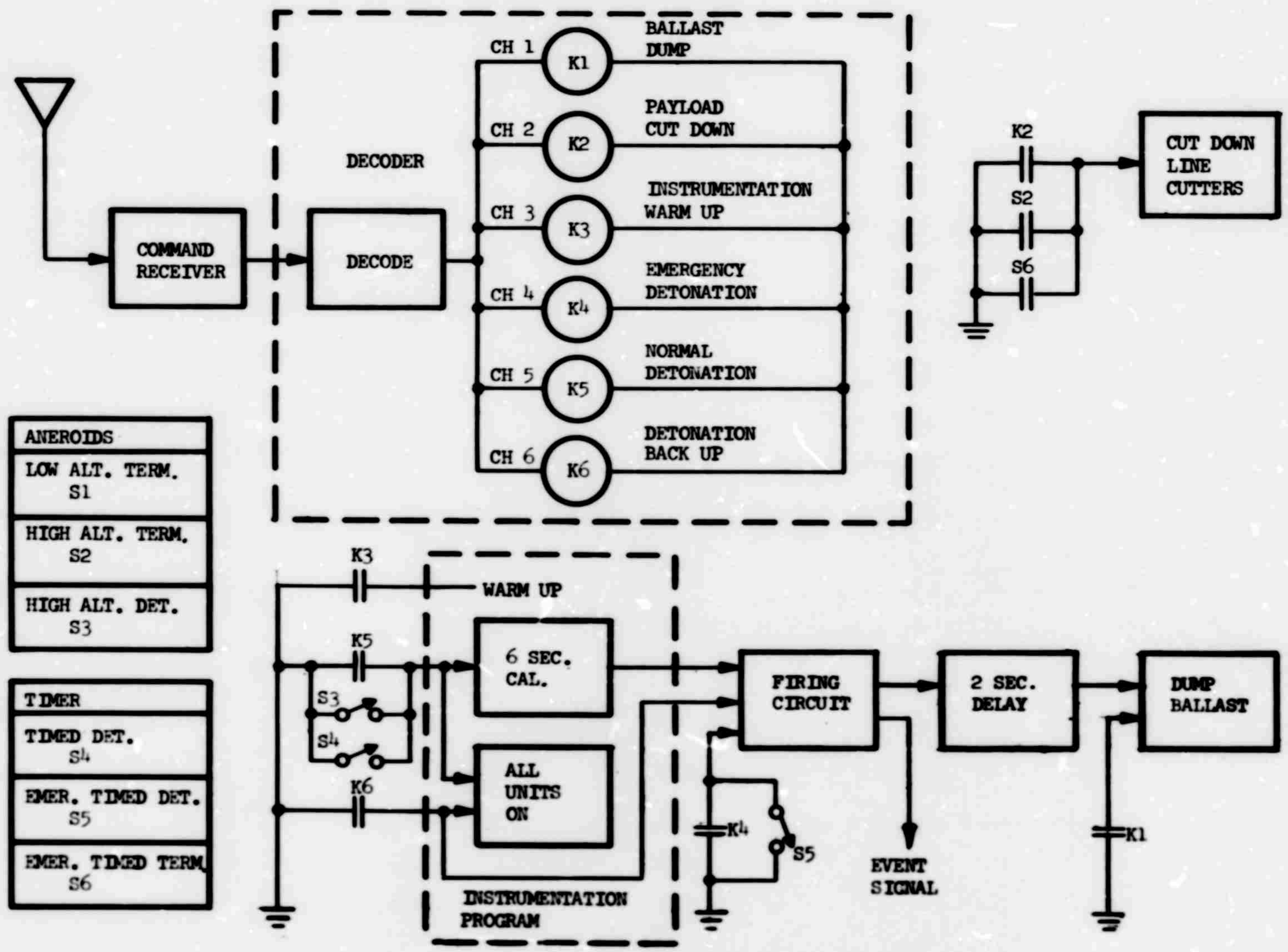


Figure 2.16 TYPICAL MULTIPLEX SYSTEM



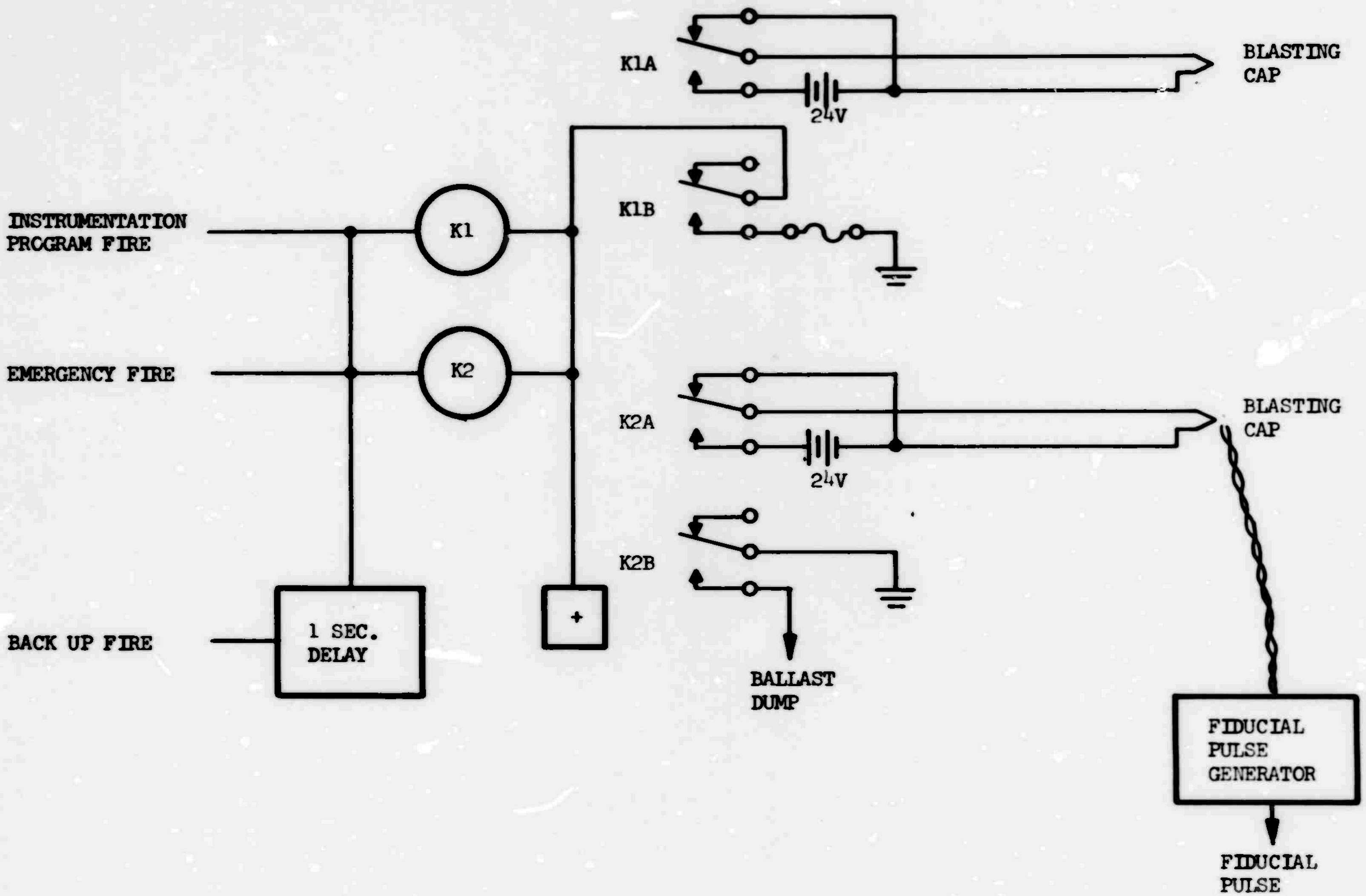
COMPLETE INSTRUMENTATION SYSTEM - BLOCK DIAGRAM

Figure 2.17



FUNCTIONAL BLOCK DIAGRAM -- COMMAND CONTROL

Figure 2.18



DETONATOR CIRCUIT AND FIDUCIAL SIGNAL

Figure 2.19

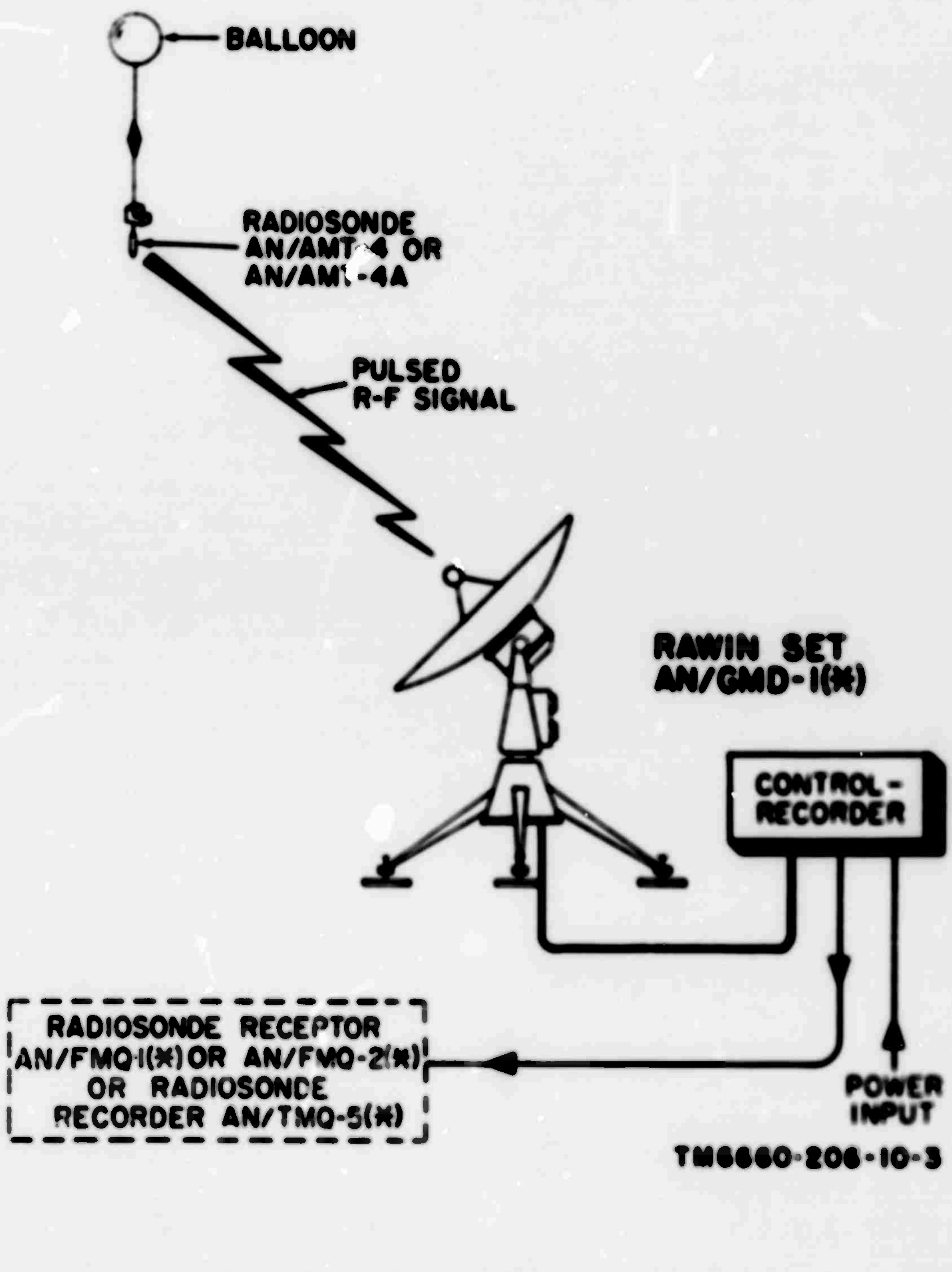


Figure 2.20 RAWINSONDE SYSTEM BLOCK DIAGRAM

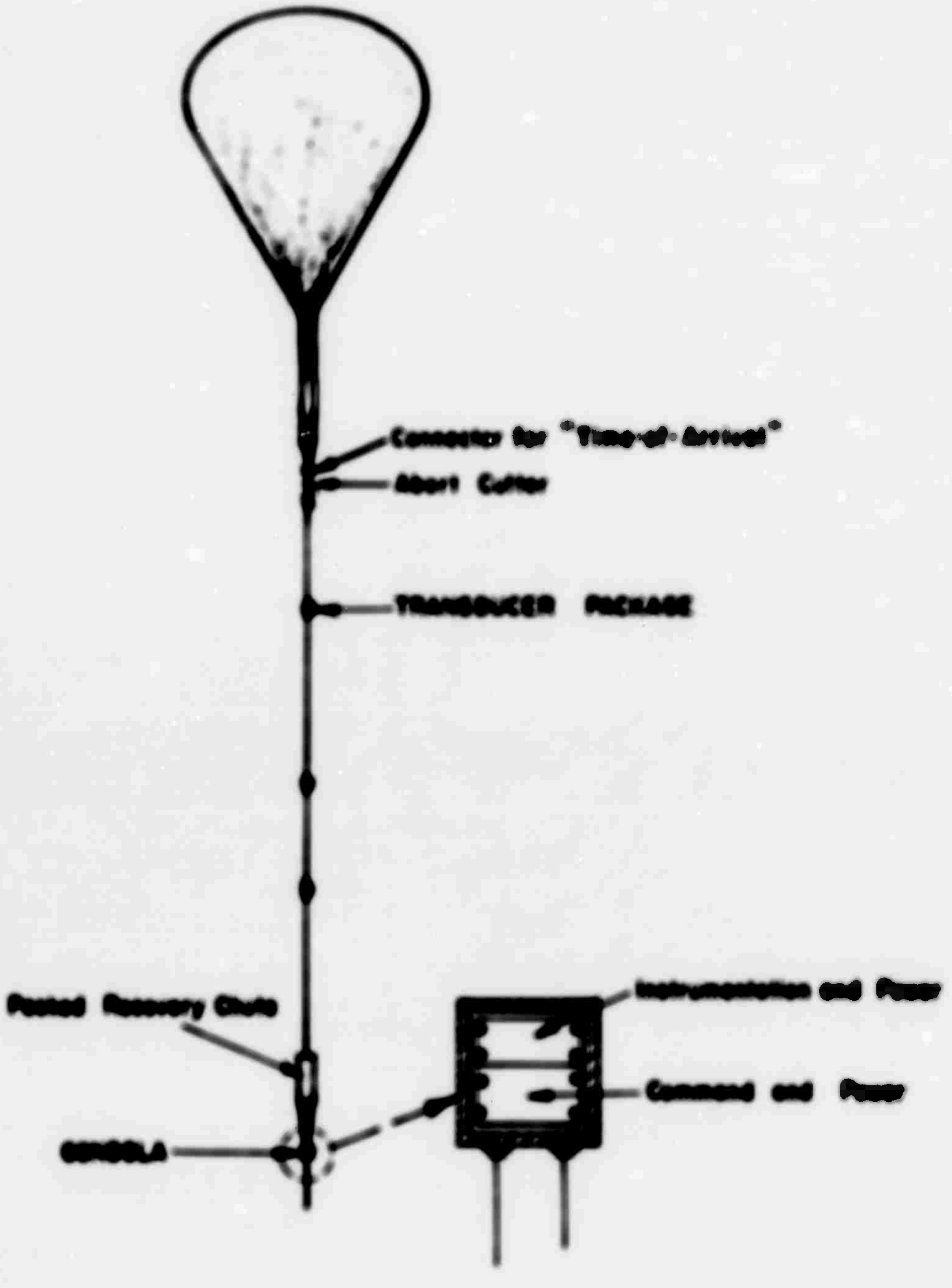
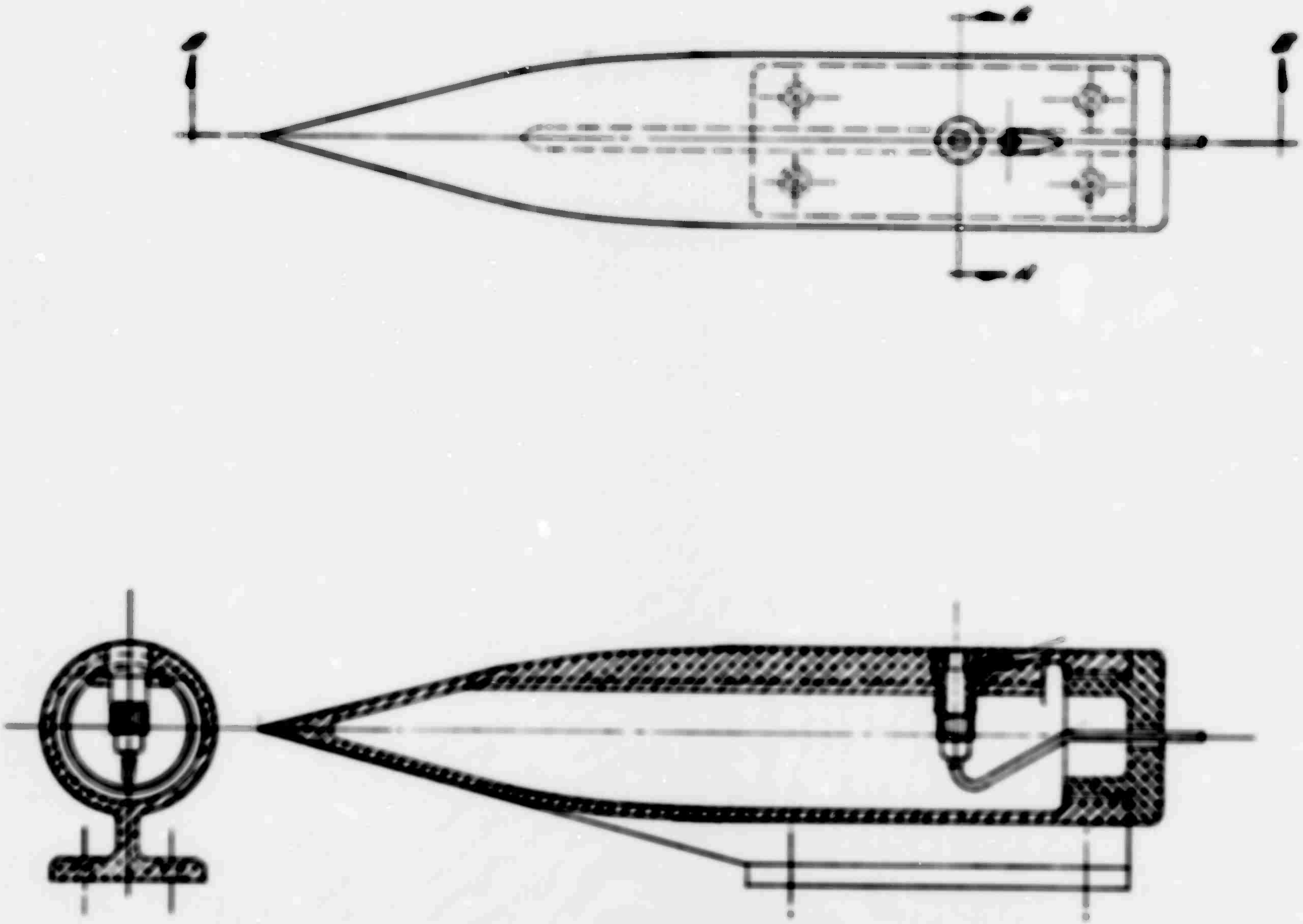


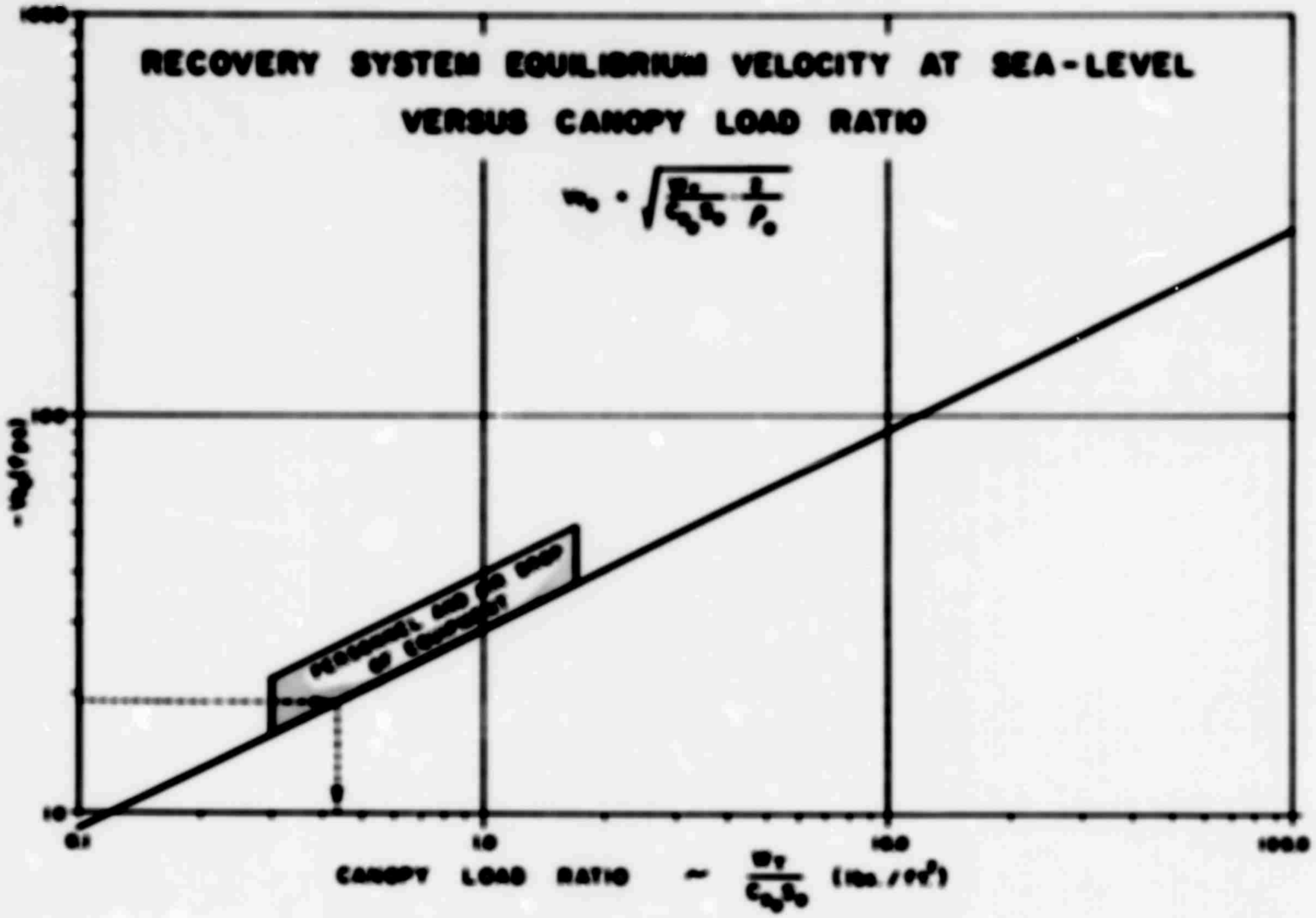
Figure 2.21 TYPICAL FLIGHT TRAIN



SECTION A-A

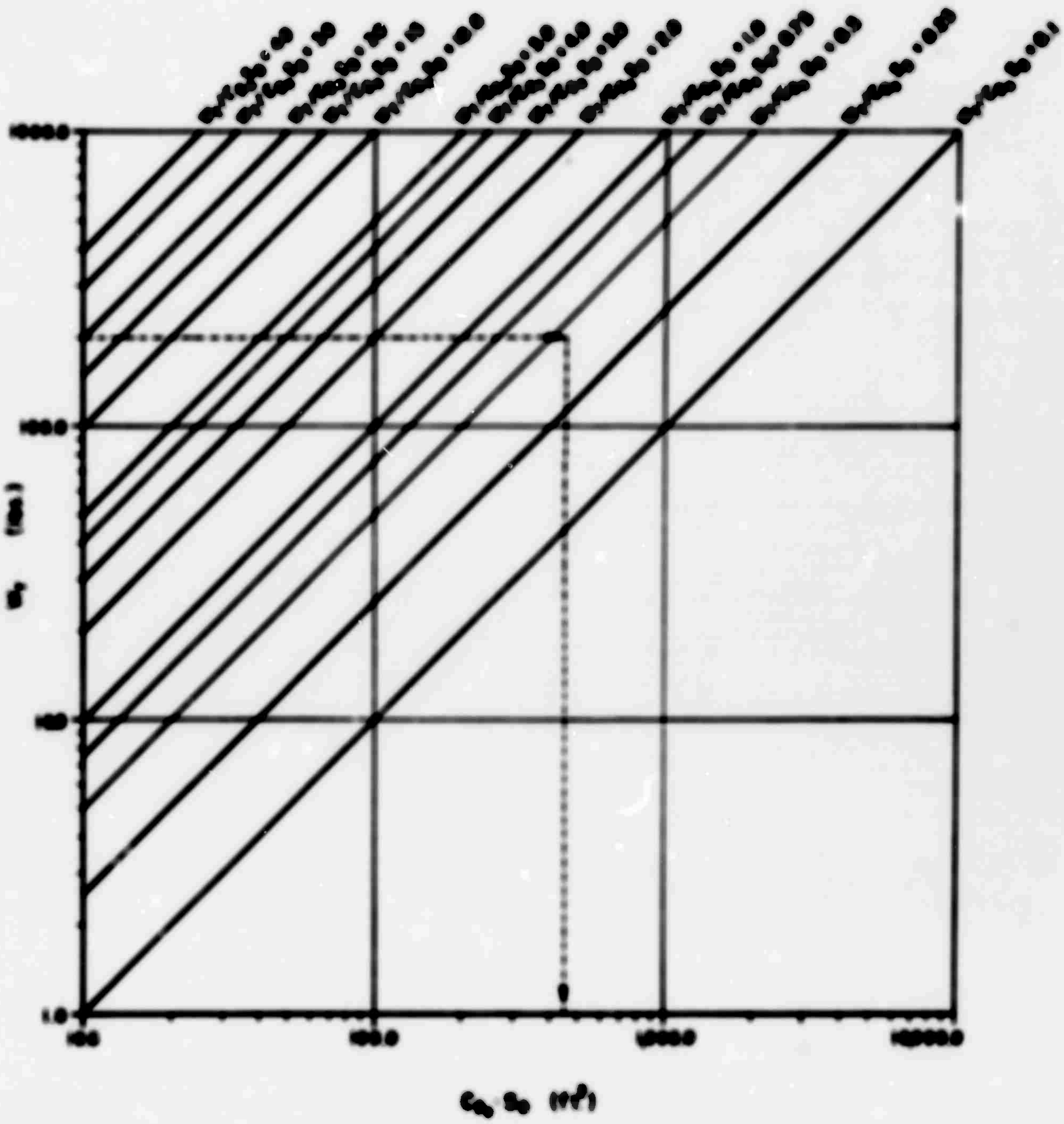
SECTION B-B

Figure 2.32 PRESSURE TRANSDUCER MOUNT



RECOVERY SYSTEM EQUILIBRIUM VELOCITY AT SEA-LEVEL
VERSUS CANOPY LOAD RATIO
$w_e = \sqrt{\frac{W_T}{C_{D_0} S_0} \cdot \frac{2}{\rho_0}}$
PERSONNEL AND AIR DROP OF EQUIPMENT
1000
100
10
1.0
CANOPY LOAD RATIO ~ $\frac{W_T}{C_{D_0} S_0}$ (lb./ft²)

Figure 2.23



RECOVERY SYSTEM TOTAL WEIGHT (W_T) VERSUS CANOPY NOMINAL DRAG AREA ($C_{D_o}S_o$) FOR VALUES OF CANOPY LOAD RATIOS ($W_T/C_{D_o}S_o$)

Figure 2.24

PARACHUTE NOMINAL DRAG COEFFICIENT (C_{D_0}) VERSUS NOMINAL CANOPY AREA (S_0) FOR VARYING VALUES OF NOMINAL DRAG AREA ($C_{D_0}S_0$)

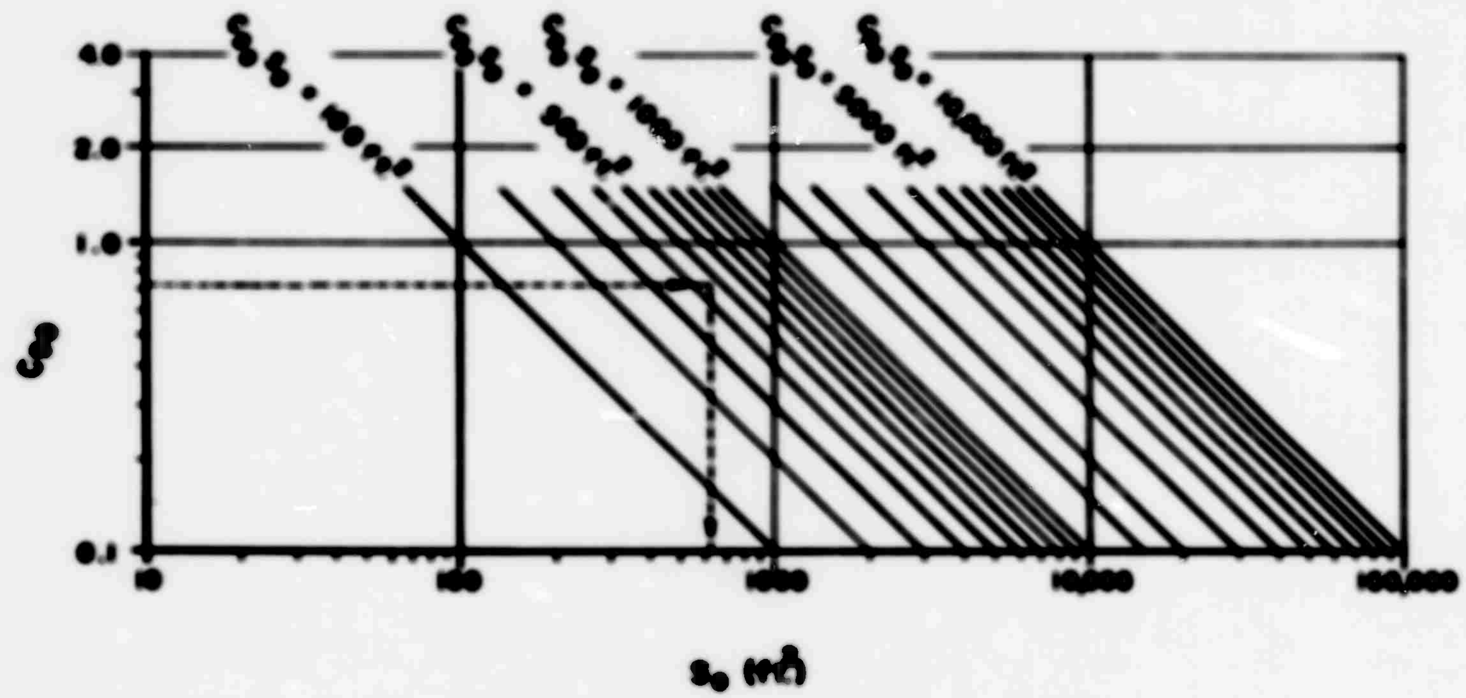


Figure 2.25

PARACHUTE NOMINAL AREA (S_o) VERSUS NOMINAL & CONSTRUCTED DIAMETERS (D_o & D_c)

(D_o = 1.24 D_c)

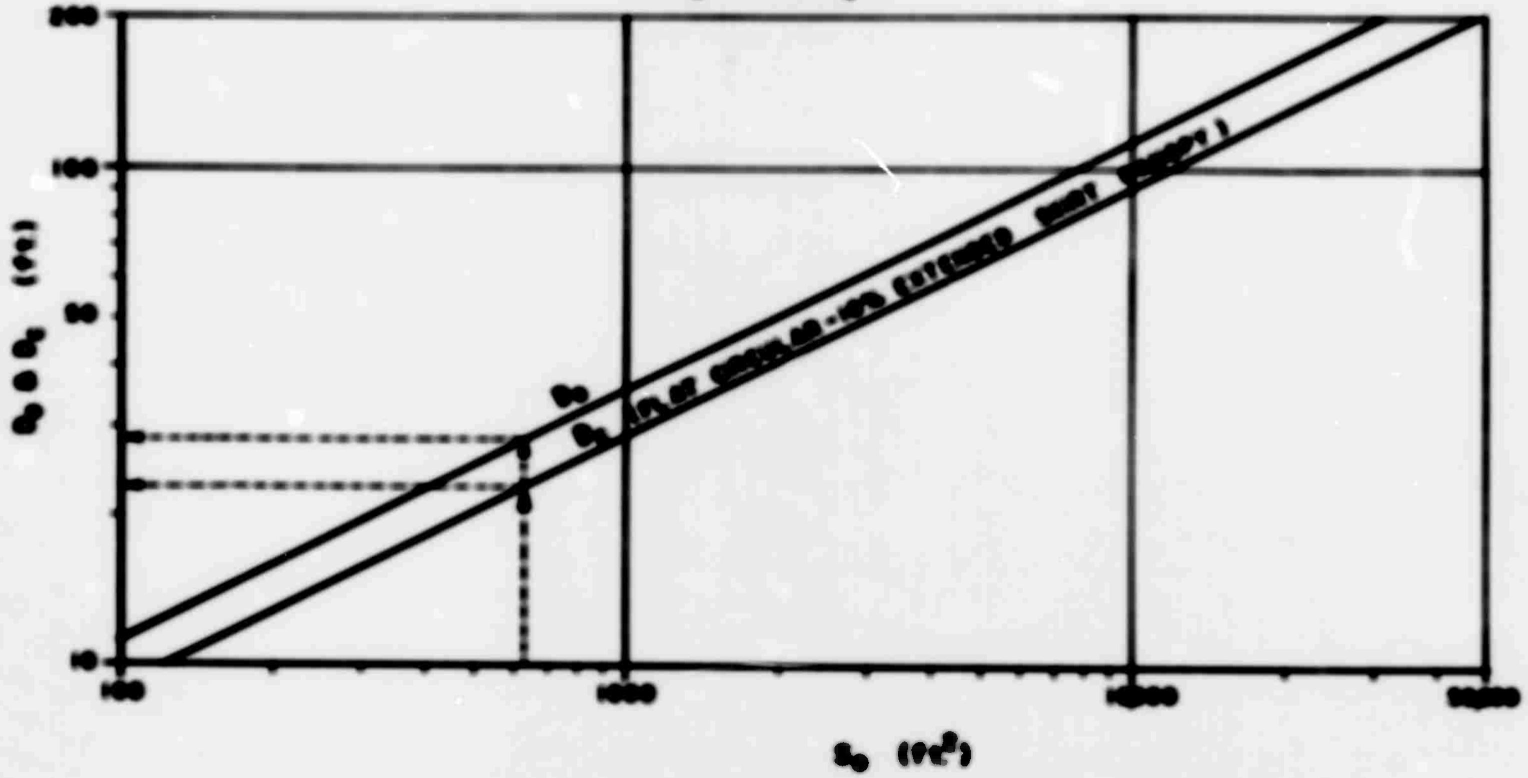


Figure 2.26

PARACHUTE NOMINAL DIAMETER (D_o) VERSUS PARACHUTE WEIGHT (W_p)

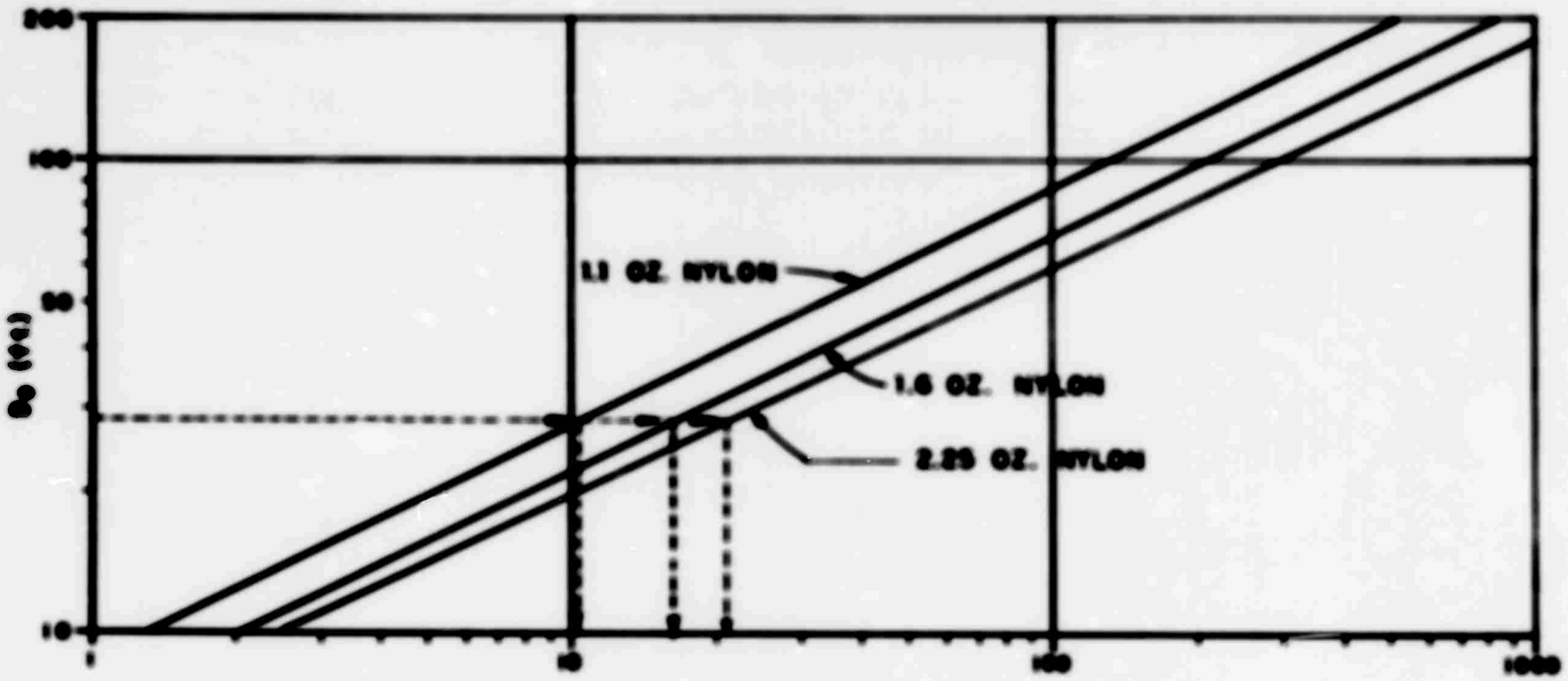
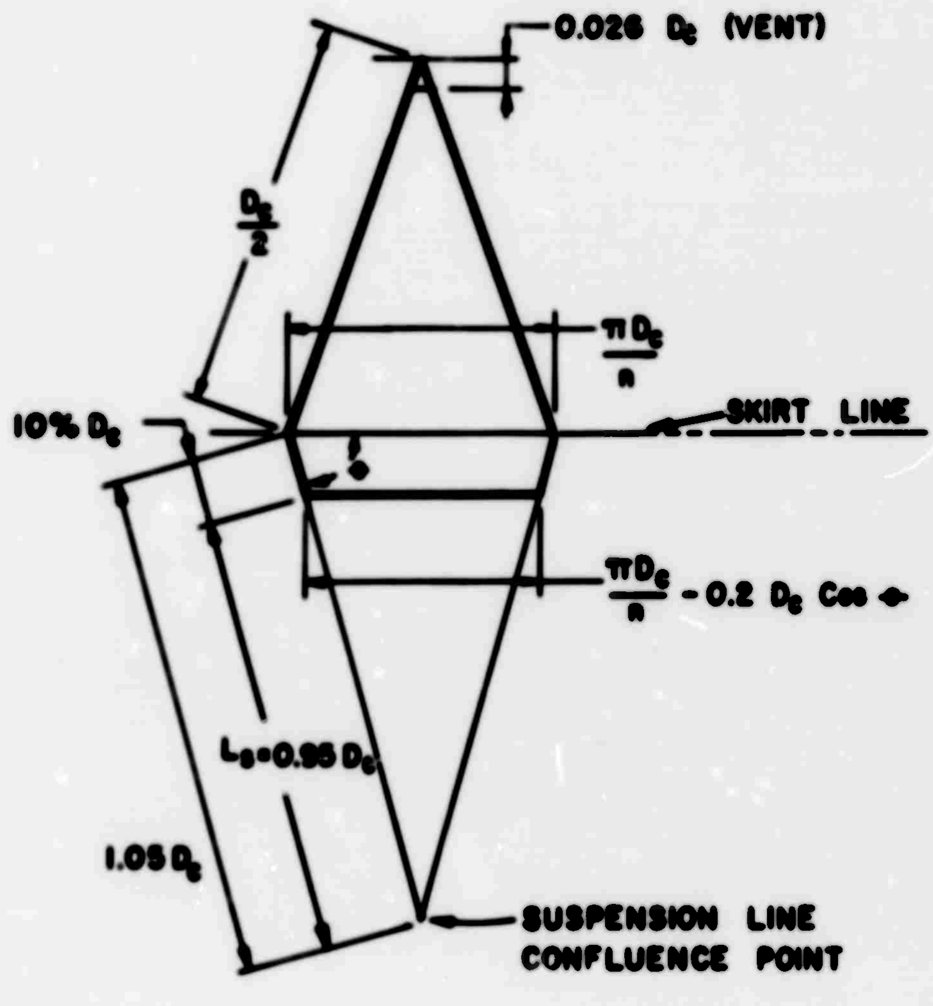


Figure 2.27



GORE PANEL FOR 10% EXTENDED SKIRT
FLAT CIRCULAR CANOPY

Figure 2.28

PARACHUTE COST VERSUS CONSTRUCTED DIAMETER (D_c) 10% EXTENDED SKIRT FLAT CIRCULAR TYPE

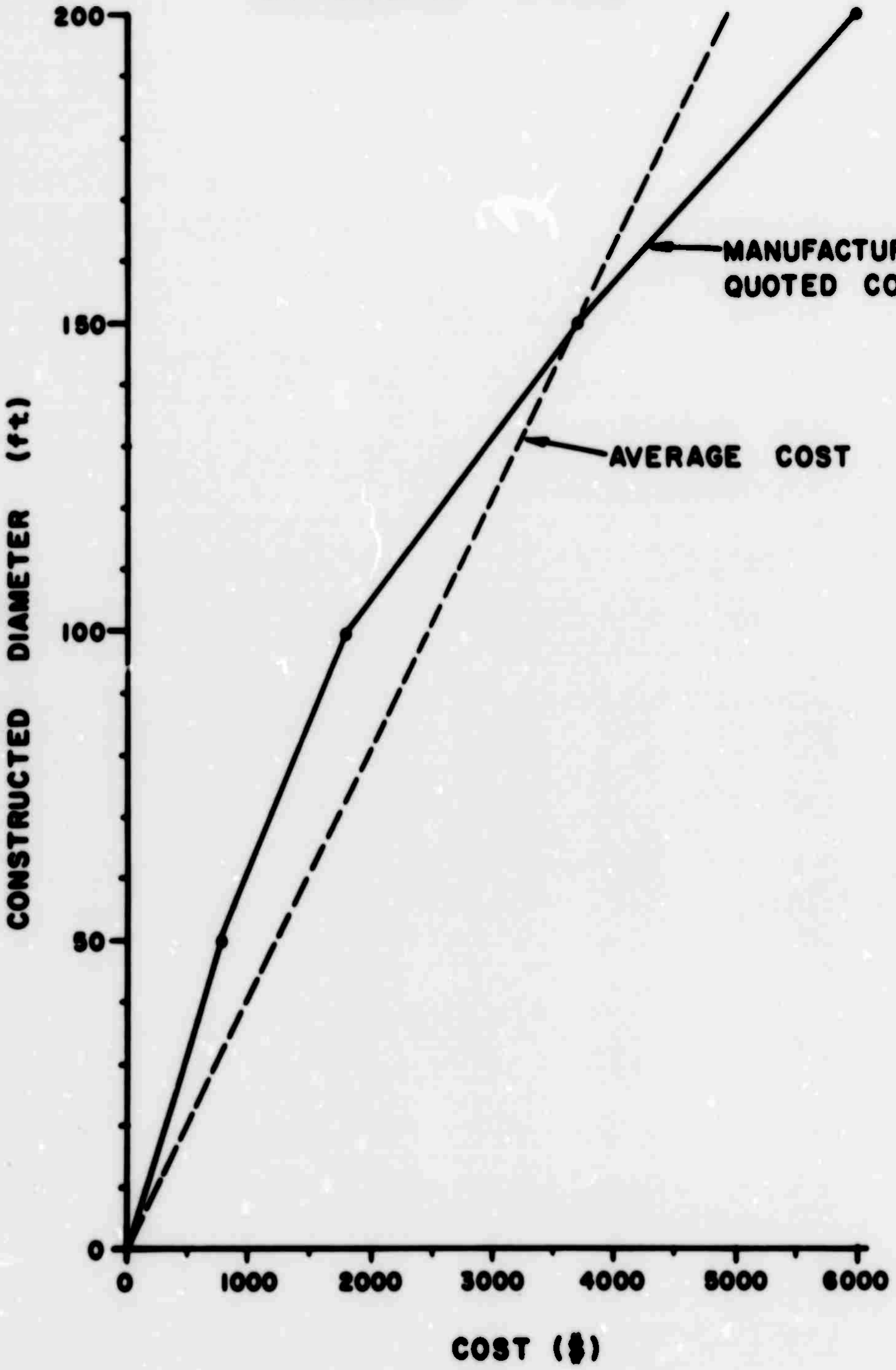


Figure 2.29

RADAR REPORTING NETWORK

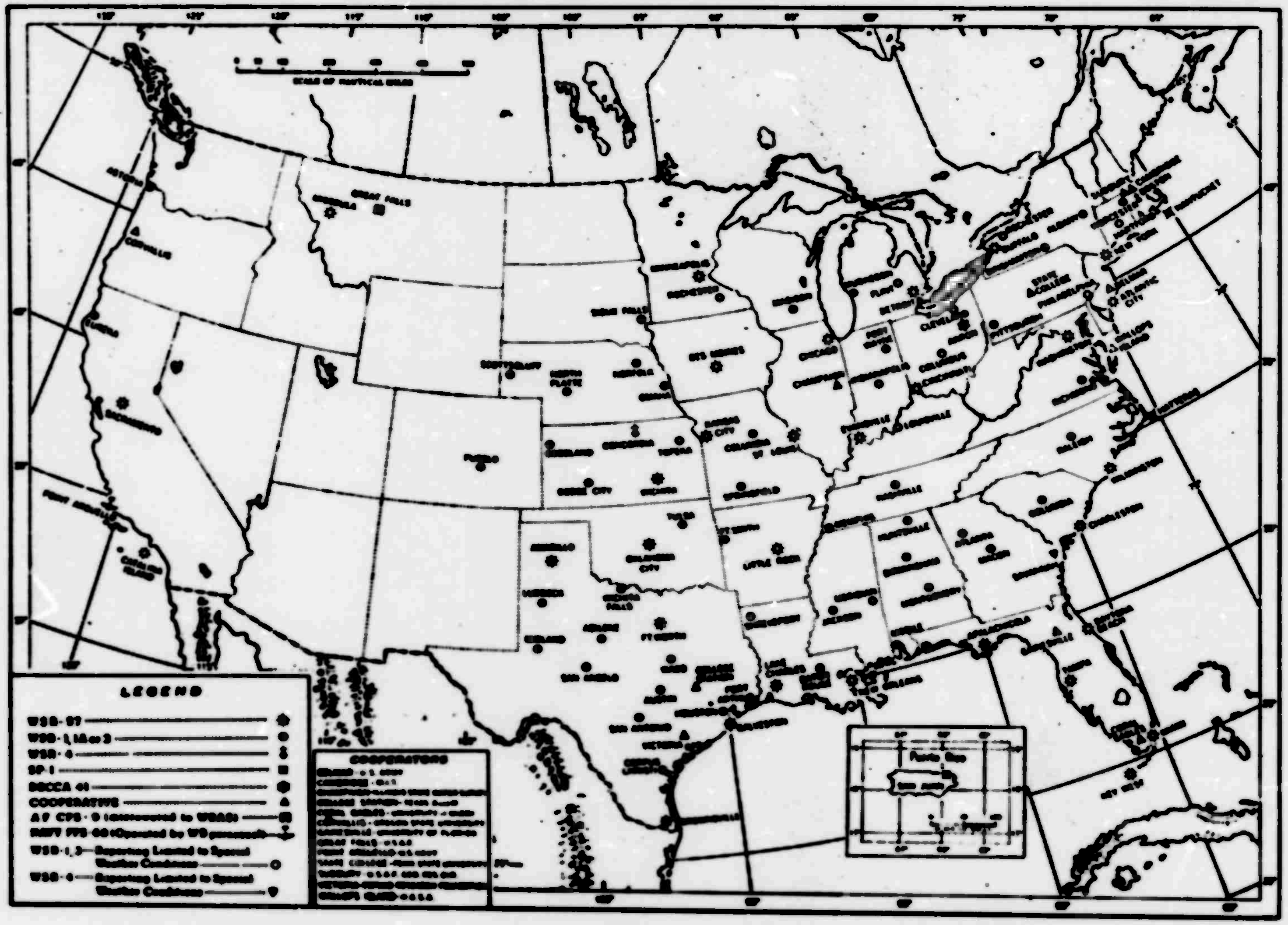


Figure 2.30

WEATHER SERVICES AVAILABLE TO LAND AND SEA BALLOON LAUNCH OPERATIONS

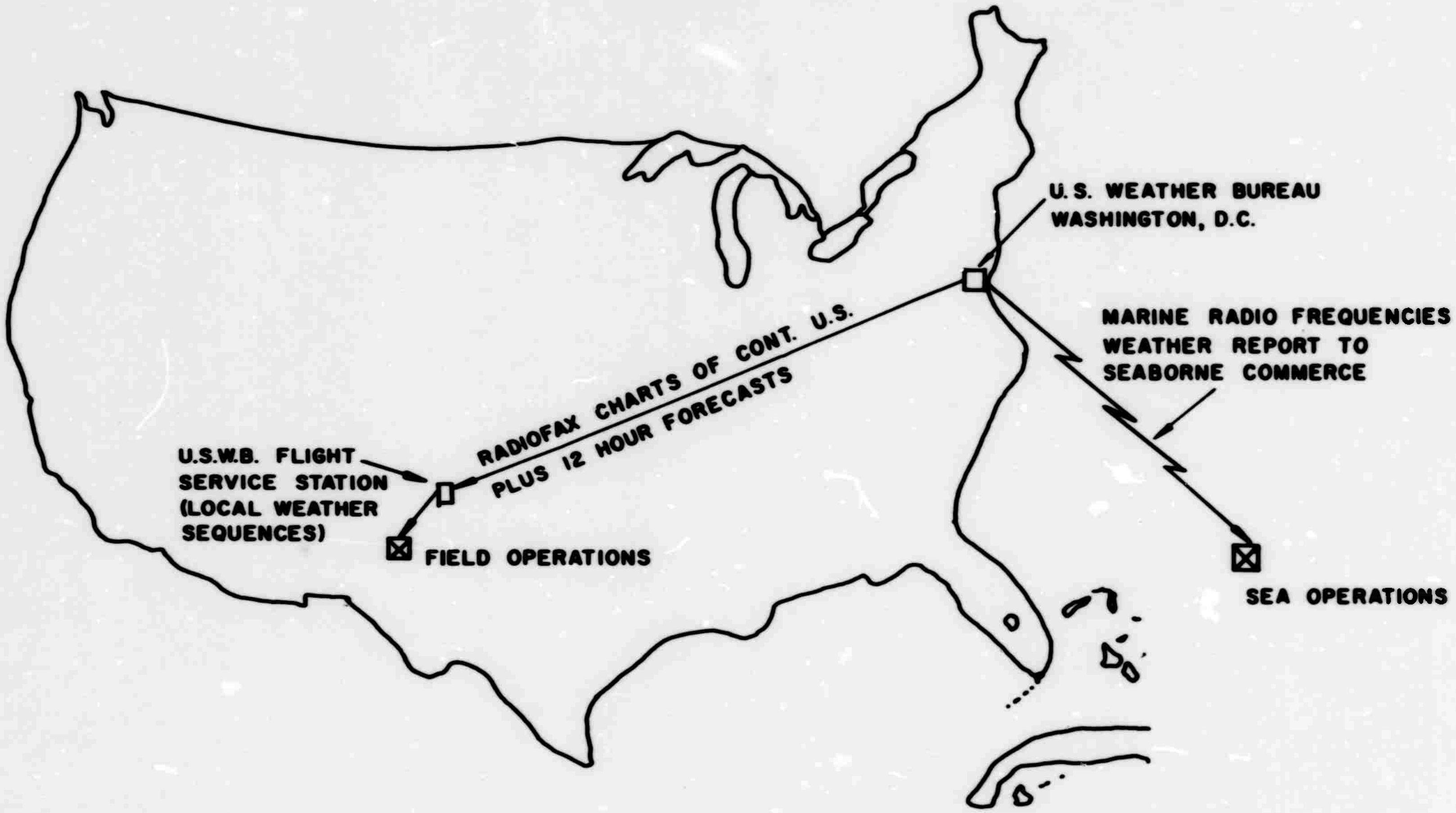


Figure 2.31

TABLE 2.1

D.C. AMPLIFIER SPECIFICATIONS

Manufacturer	Model No.	Input Sens.	Input Imped.	Gain	Freq. Resp. 3 db.	Dimensions (Inches)	Weight	Power Requirements	Unit Price
Endevco	4620	5 mv.	1 meg.	1000	dc to 10kHz	7 x 3 x 15	9.6 lb	115V 60Hz	$750.00
Dynamics Instruments	7514A	5 mv.	10 meg.	1000	dc to 75kHz	5-1/4 x 1-3/4 x 18	6.5 lb	115V 60Hz	$430.00
CEC	1-165A	5 mv.	1 meg.	1000	dc to 40kHz	5-1/4 x 1-3/4 x 15	2.5 lb	115V 60Hz	$465.00
Hewlett Packard	8875A	5 mv.	20 meg.	1000	dc to 75kHz	4-3/4 x 1-9/16 x 15	3.5 lb	115V 60Hz	$495.00
Hewlett Packard Excitation Unit	2480A	- -	- -	- -	- -	5-1/4 x 1-9/16 x 15	3.8 lb	115V 60Hz	$360.00
*DAQ-PAC	1062	5 mv.	50K	500	dc to 40kHz	2 units 3-1/8 x 3-1/2 x 6 3-5/8 x 1 x 7	8 oz	28V dc	$1500.00
*Genisco	23-150 -1	5 mv.	50K	100	dc to 20kHz ± 0.5 db	3/4 x 2-3/8 x 3-7/16	6 oz	28V dc	$760.00

*Units Include Excitation Supply

TABLE 2.2

TAPE RECORDER SURVEY

Manufacturer	Model	Remarks	No. Tracks	Top Speed ips	Size Inches	Weight lbs.	Power Source	Power Consump. Watts	Environ.	Price
Concertone	E-66	Direct R SN 25db FM SN 750db	14	30;60	12 x 10	16 lbs.	28V DC	42W +10W for heaters	-18°C -65°C w/ heaters	$18,000
Genisco	10-110	Center Freq. 108kHz	14 1" tape	30;60; 120	4 x 8-1/8 x 12	15 lbs. Trans. only. 28 lbs. Complete	28V DC	75W @ 60 ips	-40°C	$22,000
Kinelogic	LR	Center Freq. 216kHz	14	60	Trans: 7 x 6 x 4 2 Electronics packages @ 4 x 2-1/2 x 9-1/2	5-1/2 Recorder Only	28V DC	45W + 100 for heaters	-54°C to + 77°C	$24,000 ± 10% 10 channels F.M.
Leach	MTR-1200	Center Freq. 206kHz	14	60	10-1/2 x 7-1/2 x 5-1/2	55 lbs.	28V DC	96W for Transport	150,000 ft. for 20 hrs.	$24,000

TABLE 2.3

COMMAND RECEIVER SURVEY

Manufacturer	Frequency	Environment	Power Req.	Size	Weight	Price
R. S. Electronics Model 2624 & 1805	400-550 MHz. FM	Satellite	22-30 V. @ 20 ma. plus 6 ma per channel	3 x 5 x 3" 6 channels	2.5 lbs.	$1,200
Control Science Corporation	406-450 MHz. (others also)	Satellite	12 V. 22 ma plus 20 ma/ channel	5 x 6 x 1-1/2" 3 channels	2.5 lbs.	$5,500
AEL, Inc.	400-550 MHz	Satellite 100 g shock 30 g vibration -55° to + 71°C	15 to 28 V @ 22 ma	5 x 4 x 3-1/2" 8 channels	2.5 lbs.	$4,000

TABLE 2.4

BALLOON TRACKING SYSTEMS

Equipment Designation	Description	Accuracy Angle	Accuracy Range	Transportability
AN/FPS-16	Precision C-Band Monpulse Radar	0.2-0.3 mil	5-15 yds.	Fixed
AN/MPS-25	Mobile Version of FPS-16	0.2-0.3 mil	5-15 yds.	Mobile
AN/MPQ-12, AN/MPQ-18	S-Band Tracking Radar, Modified SCR-584	1.0 mil	25 yds.	Fixed
AN/MPG-2	X-Band Tracking Radar	1.0 mil	25 yds.	Fixed
TRADEX	High Resolution Tracking Radar, Long Range	0.2 mil	2 yds.	Fixed
AN/FPS-62	Advanced Re-entry Radar, Long Range, High Velocity	0.2-0.4 mil	30 yds.	Fixed
AN/FPQ-6	Second Generation Precision C-Band Tracking Radar, 32,000 n. mi. Range	0.5 mil	2 yds.	Fixed
AN/TPQ-18	Transportable AN/FPQ-6	0.5 mil	2 yds.	Transportable
DOVAP	Doppler CW-Tracking System	- -	0.4-15 ft.	Fixed

TABLE 2.4 CONTINUED

Equipment Designation	Description	Accuracy: Angle	Accuracy: Range	Transportability
SECOR	CW-Tracking, Range Triangulation	- -	1.0 ft.	Fixed
Minitrack	Radio Angle Tracking	0.1 mil	- -	Fixed
Cinetheodolite	Optical Tracker: Triangulation	[± 2-5 ft. @ 25,000 ft. ± 10 ft. @ 50,000 ft. ± 20 ft. @ 60,000 ft.]*		Transportable, Fixed
Ballistic Camera	Wide-field Plate Camera	15-45 sec 2-10 sec		Transportable, Fixed
SCR-658	Early Radiotheodolite	0.15°		Transportable
AN/GMD-1	Radio Direction Finder, Rawin Set	0.05°		Transportable
AN/GMD-2	Rawin Set with Range Adjunct	0.05°	25 yds. or 0.2% of range	Transportable
WBRT-60	Weather Bureau Radiotheodolite	0.03°	25 yds.	Fixed

*Position Accuracy: Cartesian

SECTION 3

RECOMMENDATIONS

The conceptual design and economic study conducted in this report has indicated that feasibility of a high altitude blast generation system using detonable gases contained in balloons. There is however, further development that must be accomplished before an operational system of this type can be realized. The following specific tasks are recommended for future work.

1. Conduct a study to establish a preliminary design for the complete SLEDGE-HI system and further investigate those areas of materials, techniques and gas dynamics where more detailed analysis is required to verify the validity of approach. This would include experimental tests to determine if the gases, which are initially physically separated, form a homogeneous detonable mixture during ascent to altitude.

2. Perform flight system tests to prove the design and performance adequacy of the balloon, ground launch system, flight system and associated operational techniques using helium in place of the fuel gas.

3. Perform a 20 ton gas detonation at 50,000 feet to demonstrate full system performance in the simulation of large explosive detonations at high altitudes.

4. Conduct flight tests with both meteorological and SLEDGE-HI balloons to (1) establish the meteorological feasibility of accomplishing the required balloon operations at the Kwajalein Test Site (KTS) and (2) gain experience in handling logistic problems involved in accomplishing cryogenic operations in the remote KTS area.

5. Provide the shock environment by means of a 20 ton detonation at 50,000 feet for a blast intercept experiment with a missile and document and explosion environment.

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) General American Transportation Corporation General American Research Division 7449 North Natchez Ave.,-Niles, Illinois 60648	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP NA

3. REPORT TITLE

High Altitude Blast Generation System Part II Design and Economic Study

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

Richard J. Kiima
Marion J. Banaszak

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
12 Nov. '69	110	15

8a. CONTRACT OR GRANT NO. DA-49-146-XZ-573	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. ARPA Order 908	
c. Program 7F20 d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) DASA 2303-II

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Director Defense Atomic Support Agency Washington, D. C. 20305

13. ABSTRACT

A program was conducted to determine the technical and economic feasibility of a high altitude blast generation system using detonable gases contained in balloons. The purpose of this system would be to produce a blast and shock environment at altitudes of up to 100,000 feet for in-flight missile and aircraft vulnerability testing and for atmospheric nuclear blast detection studies.

This report describes the results of this program in two parts; Part I (bound separately) describes the theoretical and experimental work; Part II describes a preliminary design and economic study of the hardware required for the system. Both Parts I and II were conducted simultaneously.

For Part I, computer codes were developed to predict the detonation properties and resultant shock wave-air interaction phenomena at low ambient pressure and temperatures. An experimental program was then conducted which verified the theoretical predictions by detonating 5 and 10 foot diameter balloons filled with either methane-oxygen or hydrogen-oxygen mixtures at simulated altitudes up to 100,000 feet (low temperatures were not simulated).

For Part II, attention was given to the balloon design, the gas handling system, the launch and handling equipment, the effects instrumentation and flight control, the instrumentation recovery system and possible test sites required to physically implement this blast and shock generation technique. Cost estimates to field a single test ranged from $191, 460 for a one ton explosive yield equivalent to 50,000 feet to $317,200 for a twenty ton yield at 50,000 feet.

DD FORM 1 NOV 65 1473

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
High Altitude Blast Generation						
Detonable Gas Explosions						
Air Blast						
Detonation Waves						
Shock Waves						